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WATER QUALITY SUBGROUP REPORT

NORTHERN GREAT PLAINS RESOURCES PROGRAM

PREPARED FOR
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Assess the possible water quality impacts of coal and related energy development upon the following water systems, the Yellowstone, the Bighorn River Basin, the Tongue River Basin, the Powder River Basin, the Cheyenne River Basin, the Belle Fourche River Basin, the Mainstem of the Missouri in North Dakota, the Little Missouri River Basin, the Heart River Basin, the Knife River Basin, and the Cannonball River Basin. Presents the present (1973-4) water quality of those streams most likely to be affected by such development. Discusses needs for water use in coal development and water quality impacts most likely associated with development. Shows critical areas where new data should be collected to insure that any development proceeds with minimum adverse impacts in both the short and long term. Discusses quality of waters discharged from energy developments. Addresses qualitative impacts on ground water.

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Surface Water	Limnology
	Trace Elements

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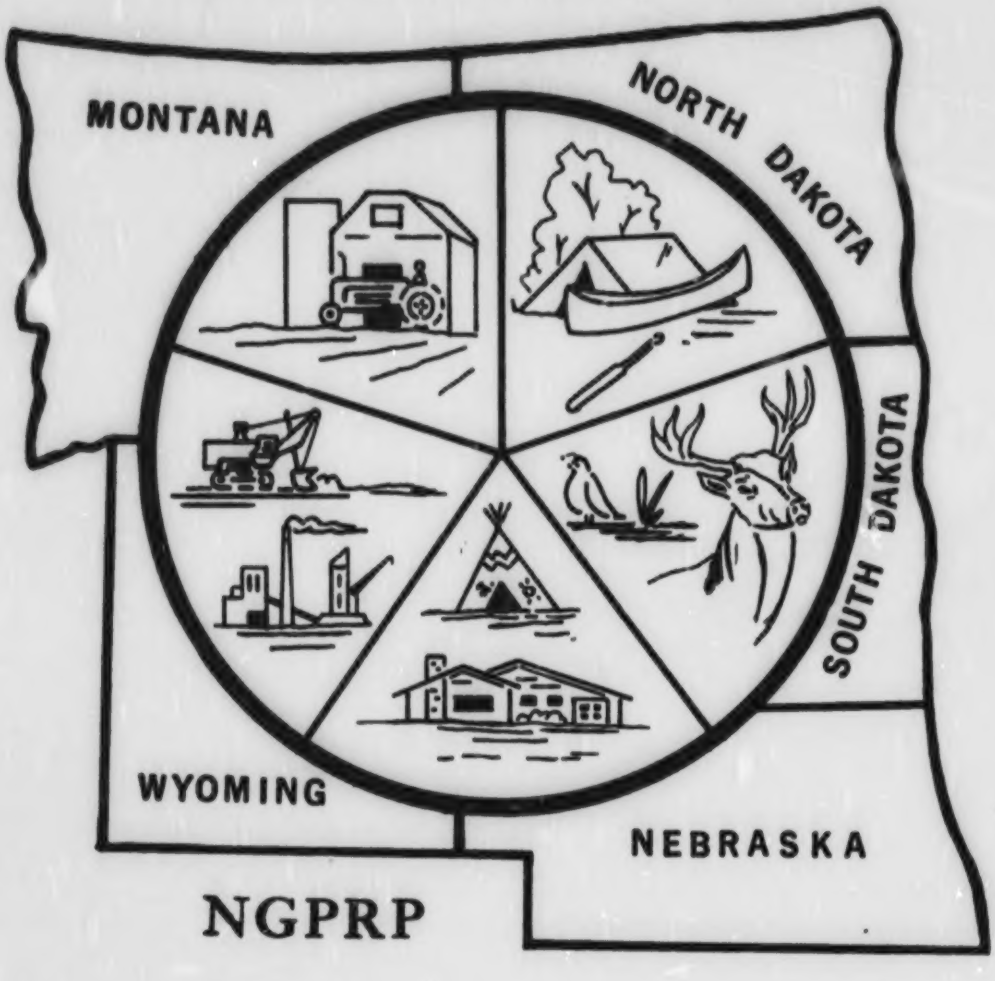
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DEPARTMENT OF INTERIOR

612

NORTHERN GREAT PLAINS RESOURCES PROGRAM

WATER QUALITY SUBGROUP

DISCUSSION DRAFT

AUGUST 1974

THIS REPORT WAS PREPARED PURSUANT TO A DIRECTIVE DATED OCTOBER 23, 1973, FROM THE PROGRAM MANAGER, NORTHERN GREAT PLAINS RESOURCES PROGRAM. PUBLICATION OF THE FINDINGS AND RECOMMENDATIONS HEREIN SHOULD NOT BE CONSTRUED AS REPRESENTING EITHER THE APPROVAL OR DISAPPROVAL OF THE SECRETARY OF THE INTERIOR, THE SECRETARY OF AGRICULTURE, THE ADMINISTRATOR OF THE ENVIRONMENTAL PROTECTION AGENCY, OR THE STATES OF MONTANA, NEBRASKA, NORTH DAKOTA, SOUTH DAKOTA, AND WYOMING. THE PURPOSE OF THIS REPORT IS TO PROVIDE INFORMATION AND ASSISTANCE TO THE PROGRAM MANAGEMENT TEAM IN THE PREPARATION OF THE DRAFT INTERIM REPORT ON THE NORTHERN GREAT PLAINS RESOURCES PROGRAM. THE PROGRAM MANAGEMENT TEAM IS RELEASING THIS DRAFT FOR PUBLIC USE WITHOUT CORRECTING INCONSISTENCIES OR REWRITING BECAUSE THE DELAY REQUIRED TO ACCOMPLISH THIS TASK WOULD DELAY THE TIMELY ISSUANCE OF THE REPORTS. THIS REPORT HAS BEEN REVIEWED BY THE WATER QUALITY SUBGROUP. MENTION OF TRADE NAMES OR COMMERCIAL PRODUCTS DOES NOT CONSTITUTE ENDORSEMENT NOR DOES IT INDICATE A SINGLE SOURCE.

PREFACE

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To all of these hard workers go our sincerest thanks and our encouragement to continue the effort to obtain sufficient information upon which good decisions can be based.

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Introduction

> "The Northern Great Plains, an area which consists of large segments of Montana, Wyoming, North Dakota, South Dakota, and Nebraska, has been the focus of increasing attention because the area is a potential source for vast amounts of relatively low sulfur coal. Interest in the development of the Northern Great Plains coal resources stems primarily from the continuing growth of national energy consumption and increasing emphasis on improved urban air quality. The possibility of large scale development of coal reserves has, at the same time heightened regional concern for effective land use and resource planning, including such issues as environmental quality, mined area reclamation, competition for scarce water resources development of other mineral resources, and potential effects on the people and economics of the Northern Great Plains States."

The statement is taken from the introduction of the Outline of Plan, for the Northern Great Plains Resources Program (NGPRP). "The primary objective of the NGPRP is to provide an analytical and informational framework for policy and planning decisions at all levels of government." Within the program seven work groups have been identified. One of these work groups, the Water Work Group, has the responsibility for assessing the impact of coal and other resource development on the water resources of the area. The study area defined for the NGPRP, and the Water Work Group includes primarily those rivers and streams in or near the Fort Union-Powder River coal deposits. The major basins in the study area include the mainstem of the Yellowstone, the Bighorn River Basin, the Tongue River Basin, the Powder River Basin, the Cheyenne River Basin, the Belle Fourche River Basin, the Mainstem of the Missouri in North Dakota, the Little Missouri River Basin, the Heart River Basin, the Knife River Basin and the Cannonball River Basin. Due to the potential for interbasin diversions to the Yellowstone drainage, other drainage systems bordering this area may be involved to some degree. These drainages include the Green River, the North Platte River, the Missouri River in Montana and South Dakota, and some tributaries of these streams. Other streams such as the Grand River and Moreau River in South Dakota may also be impacted.

Within the Water Work Group are several subgroups. The Water Quality Subgroup has the responsibility of assessing possible impacts of coal and related development upon the quality of the waters in the NGP area. The study area for this effort coincides with the principal area described above for the Water Work Group. No detailed analyses of water quality presently or projected is given for the Grand, Moreau, Upper Missouri, Lower Missouri, Green, or North Platte Rivers, as these waters have not been deemed necessary to provide the water needed to meet the projected development scenarios upon which the NGPRP is based to date. There may, however, be increasing pressure brought to bear on exports from these watersheds.

This report will deal first with the present water quality of those streams most likely affected, next with the needs for water use in coal development, then with the water quality influences most likely associated with development, and the projected changes in water quality should coal development occur, and last with ground water quality in the NGP area. The report will attempt to show those critical areas where the existing data are insufficient for adequate analysis. This area is most critical as it shows where new data should be collected to insure that any development proceeds with minimum adverse impacts, both in the short and long term.

CHAPTER I

SURFACE WATER QUALITY, A REGIONAL PROFILE
(Present Surface Water Quality)

Chapter 1 summarizes existing water-quality related information for the Northern Great Plains (NGP). For reference, a discussion of how water quality is measured in a stream is presented. This is followed by a brief discussion of the existing water quality data collection network in the NGP, with which ambient stream chemical and physical data, biological data, and effluent data are obtained.

The majority of the chapter consists of descriptions of the eleven major rivers, and their tributaries, in the NGP. A brief discussion of the topography, land use, present water quality, and present fishery is presented for the Bighorn, Tongue, Powder, Yellowstone, Little Missouri, Knife, Heart, Cannonball, Missouri, Belle Fourche, and Cheyenne Rivers.

The water quality profiles are followed by a discussion of those man-made water quality influences expected to be dominant in the NGP as development proceeds (Chapter II). Individual discussions of water quality and irrigation, feedlots, power plants, surface mines, and municipal wastes are presented. A discussion of the most important water quality parameters associated with development in the NGP is presented in Chapter III.

I-A Measurement of Surface Water Quality in the NGP

I-A.1 Introduction

The quality of a body of water is best determined by applying standard tests to water and biological samples collected at pertinent locations within that water body. The most commonly-measured parameters used to indicate water quality may be grouped in the following general categories: 1. physical - including pH, temperature, and dissolved and suspended solids, stream bottom conditions; 2. chemical - including nutrients (nitrate, phosphate, etc.), "trace" metals (copper, zinc, etc.), salinity (sulfate, chloride, etc.) and organic material (commonly measured as biochemical oxygen demand - BOD), which may produce a depletion of dissolved oxygen (DO) in the water as the organics are reduced by bacteria; and 3. biological - bacteria and other aquatic life.

These water quality parameters are incorporated in State Water Quality Standards[1] which specify the maximum limits (and/or concentrations) permitted for all waters within the state (see Appendix I). These standards, based upon the best presently-available knowledge, are enforceable by law and provide the basis for maintaining and upgrading the overall water quality of the nation. Principal authority rests with the respective states.

In order to obtain accurate water quality determinations that are also precise, standard procedures are followed in the collection and analysis of water and biological samples. These procedures are outlined in Standard Methods for the Analysis of Water and Wastewater, 13th Edition, 1971, and Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents, EPA, 1973. Further, the selection of the actual sampling site is of extreme importance in obtaining good water quality information.

---

[1] For the applicable water quality standards for each state, the reader is referred to: (1) Montana State Department of Health and Environmental Sciences, Helena, 59601 - MAC 16-2.14(10) - 514480; (2) North Dakota Department of Health, Bismarck, 58501 - "Standards of Water Quality"; (3) Wyoming Department of Environmental Quality, Cheyenne, 82001 - "Water Quality Rules and Regulations"; and (4) South Dakota "Rules of the Board of Environmental Protection" Article 34:04, South Dakota Department of Environmental Protection, Pierre, 57501.

I-A.2 The Water Quality Data Collection System

a. The Existing Serface Water Quality Monitoring Network

The existing monitoring network consists chiefly of water quality stations operated by the Geological Survey, Corps of Engineers, EPA, and the states. The four state maps included here show the extent of these surface water quality monitoring operations (Figures I-A.2-1, I-A.2-2, I-A.2-3, I-A.2-4) in the primary areas of coal deposits. Specific locations may be determined using USGS publications or the EPA data storage and retrieval system (STORET).

The USGS operates an average of 55 water quality stations within the Northern Great Plains Region. The sampling frequency is generally monthly while the parametric coverage usually includes field measurements and common ions. Field measurements include stream flow, temperature, conductance, pH, and in some cases dissolved oxygen while common ions are Ca, Mg, Na, K, SiO_2, HCO_3, SO_4, F and Cl. In Wyoming bacteriological parameters are also routinely included.

EPA and USGS together operate an additional ten water quality stations within the Region. These stations are sampled biweekly, collecting data on field conditions and they provide samples for common ions, nutrients, bacteriological, COD, TOC and metals. These stations are part of EPA's national water quality surveillance system.

The Corps of Engineers operates several water quality stations within the Region. At these stations, field, nutrients, and common ions are sampled and analyzed monthly.

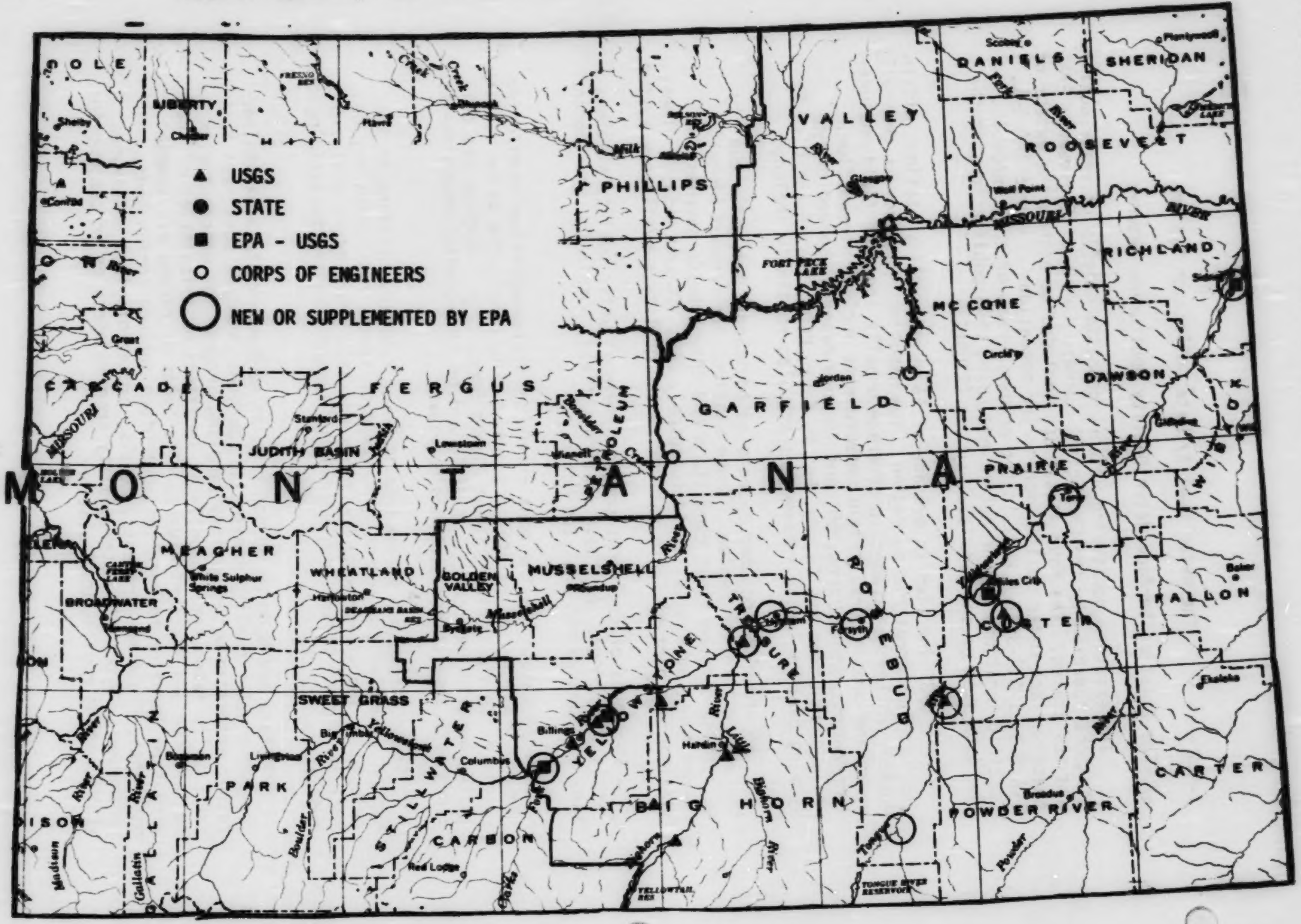
North Dakota has the most extensive State-maintained monitoring network. A total of 21 stations are used to sample the water quality of rivers in the Northern Great Plains Study Area. Samples are collected monthly and consist of field and bacteriological measurements along with some common ions and nutrients.

South Dakota has an average of seven sampling stations in the Region. Samples are generally taken each month, but months may be skipped during winter when low flows prevail. Parameters analyzed include "field" parameters, nutrients, common ions and bacteriological indicators.

Montana and Wyoming do not have an equivalent State-maintained long term water quality monitoring station. Montana does have a rather extensive water quality sampling program for which samples are usually taken semi-annually at locations on tributaries of the Yellowstone and Missouri Rivers. The types of parameters sampled vary from location to location, but often include common ions, nutrients, field measurements, metals, bacteriological and oxygen parameters. Wyoming's water quality program operates in conjunction with existing routine USGS stations.

Figure I-A.2-1

Water Quality Stations in the Northern Great Plains Region of Montana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● STATE
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○ CORPS OF ENGINEERS
◯ NEW OR SUPPLEMENTED BY EPA
M O N T A N A
TOOLE
LIBERTY
HILL
PHILLIPS
VALLEY
DANIELS
SHERIDAN
ROOSEVELT
RICHLAND
McCONE
DAWSON
GARFIELD
PETROLEUM
FERGUS
JUDITH BASIN
CASCADE
MEAGHER
BROADWATER
WHEATLAND
GOLDEN VALLEY
MUSSELSHELL
PRAIRIE
WIBAUX
FALLON
CUSTER
ROSEBUD
TREASURE
YELLOWSTONE
SWEET GRASS
STILLWATER
CARBON
BIG HORN
POWDER RIVER
CARTER
PARK
GALLATIN
MADISON
CHOUTEAU
LEWIS AND CLARK
JEFFERSON
Shelby
Conrad
Chester
Havre
Malta
Glasgow
Wolf Point
Scobey
Plentywood
Sidney
Circle
Jordon
Glendive
Terry
Baker
Ekalaka
Miles City
Forsyth
Hysham
Hardin
Broadus
Billings
Columbus
Big Timber
Livingston
Bozeman
Red Lodge
Roundup
Ryegate
Harlowton
White Sulphur Springs
Townsend
Lewistown
Stanford
Winnett
FORT PECK LAKE
FRESNO RES
CANYON FERRY LAKE
DEADMANS BASIN RES
YELLOWTAIL RES
TONGUE RIVER RESERVOIR
MISSOURI
MISSOURI RIVER
Milk
Poplar
Creek
River
Musselshell
Yellowstone
Little Bighorn
Bighorn River
Tongue
Powder
Boulder
Clarks Fork
Gallatin
Madison

Figure I-A.2-2

Water Quality Stations in the Northern Great Plains Region of North Dakota

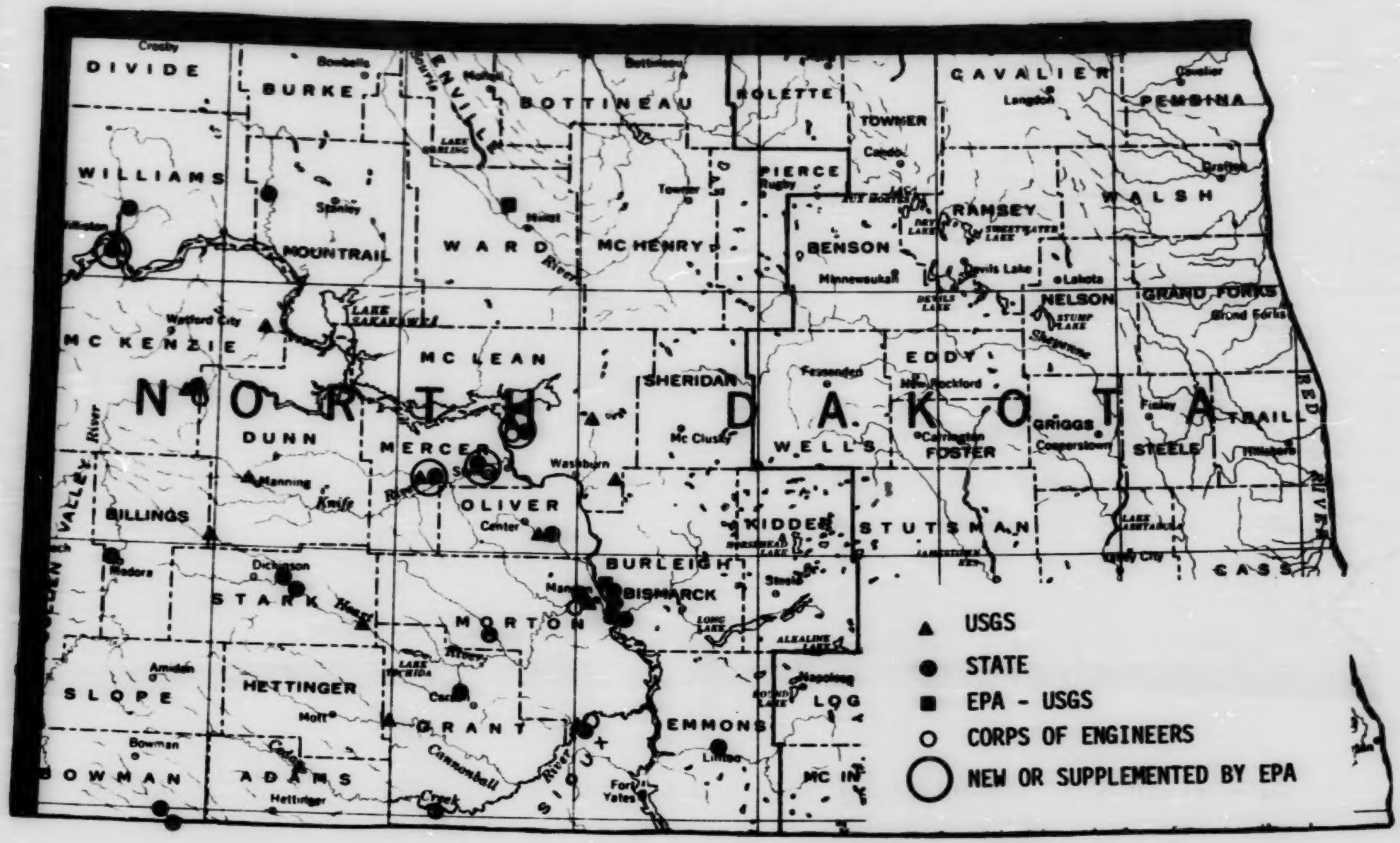
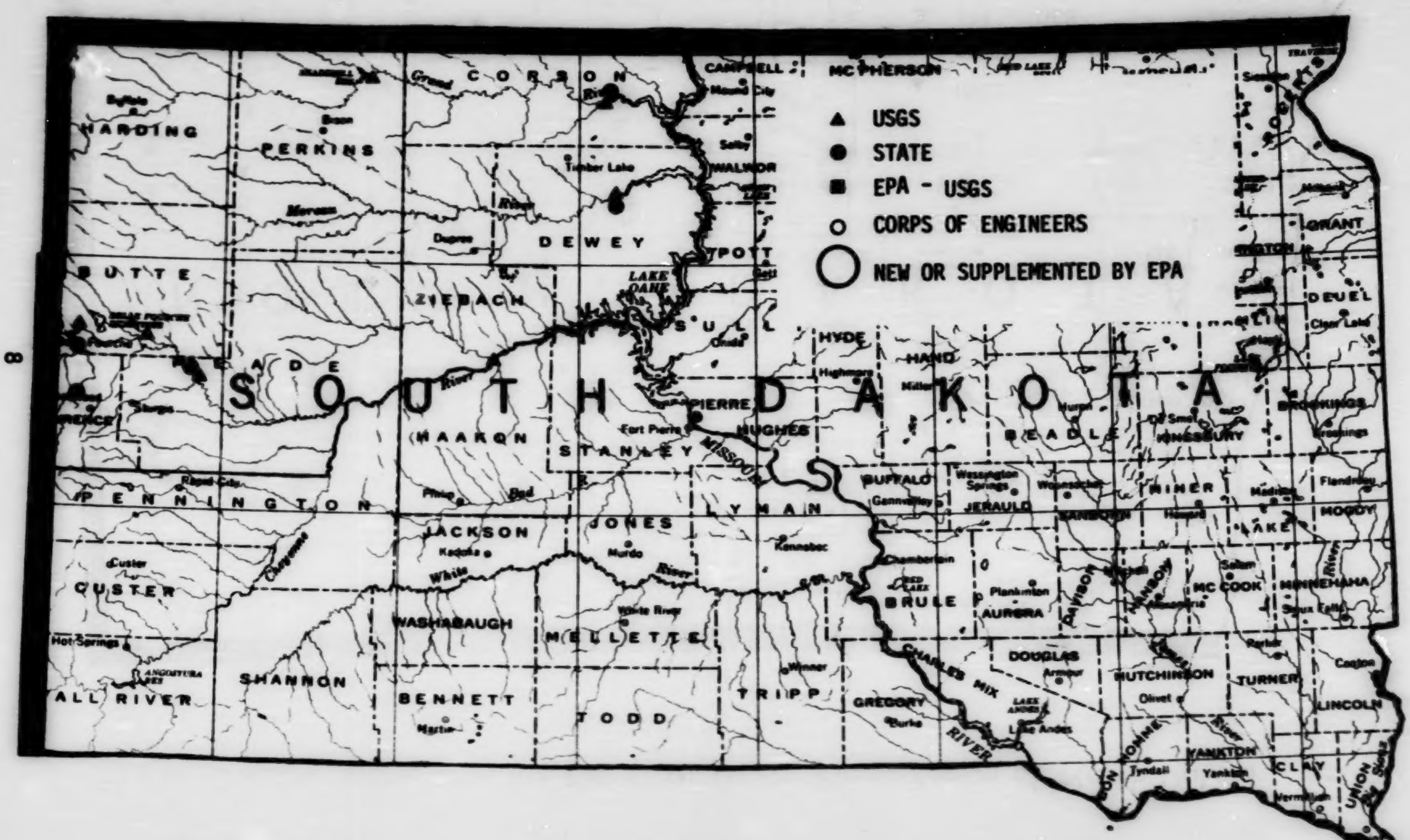

NORTH DAKOTA
DIVIDE
BURKE
BOTTINEAU
ROLETTE
TOWNER
CAVALIER
PEMBINA
WILLIAMS
MOUNTRAIL
WARD
MC HENRY
PIERCE
BENSON
RAMSEY
WALSH
MC KENZIE
MC LEAN
SHERIDAN
EDDY
NELSON
GRAND FORKS
DUNN
MERCER
OLIVER
WELLS
FOSTER
GRIGGS
STEELE
TRAILL
BILLINGS
KIDDER
STUTSMAN
BURLEIGH
BISMARCK
CASS
STARK
MORTON
SLOPE
HETTINGER
GRANT
EMMONS
BOWMAN
ADAMS
SIOUX
MC IN
LOG
RED RIVER
▲ USGS
● STATE
■ EPA - USGS
○ CORPS OF ENGINEERS
◯ NEW OR SUPPLEMENTED BY EPA

Figure I-A.2-3

Water Quality Stations in the Northern Great Plains Region of South Dakota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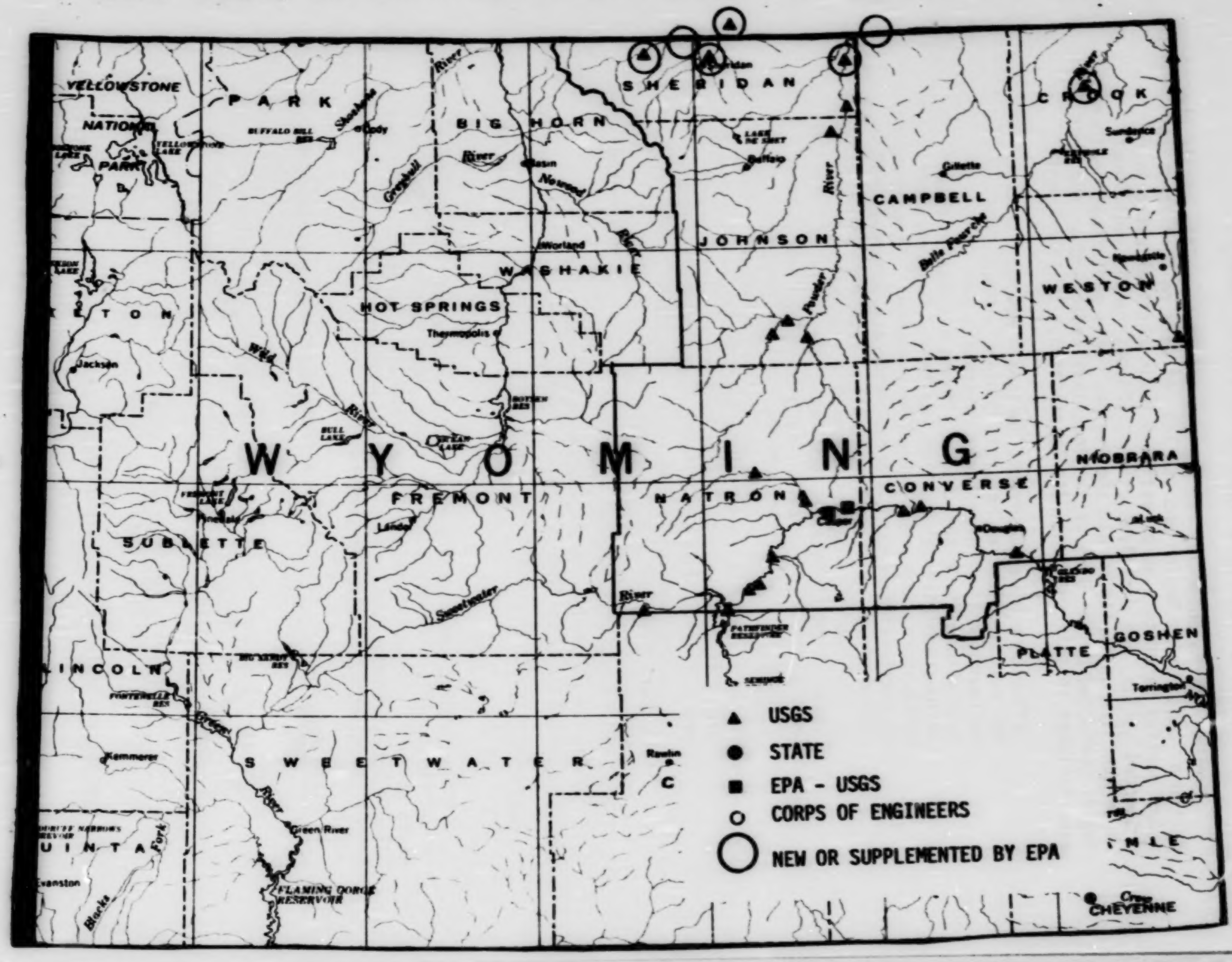
■ EPA - USGS
○ CORPS OF ENGINEERS
◯ NEW OR SUPPLEMENTED BY EPA
SOUTH DAKOTA
HARDING
PERKINS
CORSON
CAMPBELL
MC PHERSON
DEWEY
BUTTE
ZIEBACH
MEADE
HAAKON
STANLEY
SULLY
HYDE
HAND
HUGHES
PIERRE
Fort Pierre
LAKE OAHE
BEADLE
KINGSBURY
BROOKINGS
DEUEL
GRANT
PENNINGTON
Rapid City
JACKSON
JONES
LYMAN
BUFFALO
JERAULD
SANBORN
MINER
LAKE
MOODY
CUSTER
Custer
Hot Springs
FALL RIVER
SHANNON
WASHABAUGH
BENNETT
MELLETTE
TODD
TRIPP
GREGORY
BRULE
AURORA
DAVISON
HANSON
MC COOK
MINNEHAHA
DOUGLAS
HUTCHINSON
TURNER
LINCOLN
CHARLES MIX
BON HOMME
YANKTON
CLAY
UNION
MISSOURI
RIVER
White
River
Grand
Moreau
Cheyenne
Bad
Timber Lake
Murdo
Kennebec
Chamberlain
Plankinton
Winner
Burke
Lake Andes
Armour
Olivet
Tyndall
Yankton
Vermillion
Sioux Falls
Salem
Madison
Flandreau
Huron
Miller
Highmore
Onida
Philip
Kadoka
White River
Martin
Mound City
Selby
Dupree
Buffalo
Bison
Sturgis
Wessington Springs
Woonsocket
Howard
Gannvalley
Clear Lake
Canton
Parker

Figure 4.2-4

Water Quality Stations in the Northern Great Plains Region of Wyoming


YELLOWSTONE NATIONAL PARK
PARK
Cody
BUFFALO BILL RES
BIG HORN
Basin
SHERIDAN
Buffalo
CROOK
Sundance
CAMPBELL
Gillette
JOHNSON
Powder River
Belle Fourche
WESTON
Newcastle
WASHAKIE
Worland
HOT SPRINGS
Thermopolis
TETON
Jackson
WYOMING
FREMONT
Lander
NATRONA
Casper
CONVERSE
Douglas
NIOBRARA
SUBLETTE
Pinedale
LINCOLN
Kemmerer
SWEETWATER
Green River
FLAMING GORGE RESERVOIR
UINTA
Evanston
PLATTE
GOSHEN
Torrington
CHEYENNE
PATHFINDER RESERVOIR
GLENDO RES
BULL LAKE
BOYSEN RES
Rawlins
▲ USGS
● STATE
■ EPA - USGS
○ CORPS OF ENGINEERS
◯ NEW OR SUPPLEMENTED BY EPA

b. Supplemental Surface Water Quality Monitoring Network

Because of the potential for changes in water quality within the Northern Great Plains Region and the lack of data on such important water quality parameters as potentially toxic chemical elements, suspended solids, and dissolved oxygen, EPA has funded additional water quality monitoring within the Region. This additional monitoring is conducted by the USGS at the locations indicated on the four maps included in this section. The locations during 1974-5 are:

Yellowstone River at Myers, Montana - New
Yellowstone River at Forsyth, Montana - New
Yellowstone River near Terry, Montana - New
Yellowstone River near Laurel, Montana - Supplemented*
Yellowstone River at Huntley, Montana - Supplemented*
Yellowstone River near Miles City, montana - Supplemented*
Yellowstone River near Sidney, Montana - Supplemented*
Bighorn River at Bighorn, Montana - Supplemented*
Tongue River near Dayton, Wyoming - Supplemented*
Tongue River at Monarch, Wyoming - New
Goose Creek below Sheridan, Wyoming - Supplemented*
Tongue River near Decker, Montana - Supplemented*
Tongue River below Hanging Woman Creek, Montana - New
Tongue River at Brandenberg Bridge, Montana - Supplemented*
Tongue River near Miles City, Montana - Supplemented*
Powder River at Montana-Wyoming State Line - New
Clear Creek near Arvada, Wyoming - Supplemented*
Missouri River at Williston, North Dakota - New
Missouri River at Garrison, North Dakota - Supplemented*
Spring Creek at Zap, North Dakota - Supplemented*
Knife River near Hazen, North Dakota - Supplemented*
Belle Fourche River at Devils Tower, Wyoming - Supplemented*

* Additional water quality analyses are performed -- see following description.

Some of these stations are new and others are existing stations for which specific parameters are to be analyzed in addition to the existing work. These new stations are shown on Figures A.2-1 through 4. All stations, whether new or supplemented, will now be used to analyze the following water quality parameters.

- Field Measurements (Monthly) - stream temperature, conductance, pH, Dissolved oxygen;
- Laboratory Analysis (Monthly) - Cu, Mg, Na, K, SiO_2, HCO_3, CO_3, SO_4, F, Cl, Total KgN, Total NH_4, Total NO_2-NO_3, Total P, Suspended Solids, Calculated Dissolved Solids, BOD;
- Laboratory Analysis (Quarterly) - Total Pb, Total Cu, Total Hg, Total Al, Total B, Total Zn, Total Se, Total F;
- Laboratory Analysis (Annual) - Dissolved Pb, Dissolved Hg, Dissolved Al, Dissolved B, Dissolved Zn, Dissolved Se, Dissolved F.

c. Biological Data

In addition to chemical water quality data of ambient conditions in rivers and streams, data on the aquatic ecosystem can also be an indicator of water quality. Unfortunately, and unlike the network discussed for chemical water quality data, no comprehensive data collection network exists for biological water quality data. Some biological data are being collected on certain streams by State Fish and Game Departments. Generally, these data relate to the fisheries status, but they may include data collection on aquatic insects, invertebrates and other parts of the aquatic ecosystem. In addition, university researchers, State Environmental Quality Departments, EPA, and State Fish and Game Departments frequently conduct intensive, specific biological studies on short stretches of certain streams, for a variety of purposes. In this report most biological data discussed are from State Fish and Game Departments.

d. Effluent Data

There is one other data collection effort underway which relates directly to water quality. With the passage of the Federal Water Pollution Control Act Amendments of 1972 all discharges of liquid effluent into waters of the United States require a permit. This permit is issued by EPA (or the state if the program has been assumed by the state) and contains specific effluent limits. In addition, each discharger is required to set up a self-monitoring program. As time continues, it will be possible to develop a detailed inventory of all pollutants added to waters in the NGP via point discharges. An accurate inventory of this type is not possible with existing data.

Work is underway on the definition of water effluent limitations and standards of performance for the Coal Mining Point Source category. Standards have been promulgated for water effluents from Steam Electric Power Generating Point Source Category (Federal Register V39 No. 196; 36186 - 36207).

I-B

Present Surface Water Quality

In this section a current profile of 11 river drainages will be presented. The profile will include cursory information on the basin's topography, land use, water quality, and current fisheries. From the profiles it can be generally concluded that the water quality of the streams in the NGP is fair to good. This judgment, however, must be tempered with the realization that pertinent water quality information often is not generally available to adequately describe current water quality.

For the basin profiles that follow, a total of 52 water quality stations were examined. The data generally exhibited a high degree of uniformity. In some basins considerably more data were available to the water quality subgroup, than in others. All available data were utilized for the profiles, resulting in a more complete description of some basins than others. However, flow data are from the EPA STORET[1] computerized data retrieval system and are collected only when water quality is sampled. Therefore, they do not necessarily represent a comprehensive collection of flow data.

The tabular summaries of water quality data require explanation if they are to be used most effectively. The water quality stations are listed in an upstream to downstream order for each basin. Complete daily retrievals were examined for all stations, extraneous[2] values eliminated, and new mean values calculated when removal of extraneous values changed previously reported means significantly. Some reported values have been rounded off according to the following procedure: nutrient data were rounded to the nearest 0.01 mg/l, dissolved and total metals data, except fluoride, were rounded to the nearest 0.1 ug/l, except where such rounding off resulted in a value of zero. Then the reported values were retained. Footnotes applicable to Tables 1-10 are listed below:

1) Dissolved residue, dried at 180°C

2) Dissolved reside, dried at 105°C

3) Total Aluminum, ug/l

4) Total nitrate as N, converted from NO_3

5) Total phosphate as P, converted from PO_4

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[1] EPA maintains a file of water quality data, referred to as STORET (STOrage and RETrieval). The data are stored in a central computer facility which may be accessed by telephone line using low or medium speed terminals. Data are provided by numerous Federal and State entities and include information from over 200,000 stations.

[2] "Extraneous" is used to mean a high or low value that appeared to be unrealistic and may have resulted from an error in analysis or input to the data system. Less than 1 percent of the data was so affected.

6) Total mercury

7) Total nonfiltrable residue

8) Dissolved nitrate as N, converted from NO_3

9) Total filtrable residue, dried at any temperature

10) Dissolved ammonia as N, converted from NH_3

11) Orthophosphate as P, converted from PO_4 (dissolved)

I-B.1 Bighorn River Basin

a. The Basin

The Bighorn basin consists of the Wind and Bighorn River and the major tributaries, the Nowood, Greybull, Shoshone, and Little Bighorn Rivers.

The Wind River basin is the upper portion of the Bighorn basin. This upper basin drains 7,700 square miles and is bounded on the southwest by the Wind River Mountains, on the north by the Owl Creek Mountains and on the south and east by the deeply eroded Sweetwater uplift. Elevations within the basin range from the 13,785 foot Gannet Peak to under 4,000 feet. The interior of the basin is a broad dissected plain containing rolling uplands, buttes, badlands, and alluvial fans near the mountains.

The Bighorn Basin is a broad bowl-shaped area almost completely surrounded by mountains in Wyoming. Elevations range from 13,000 to 3,000 feet. The interior of the Bighorn Basin is composed of rolling hills and dissected terraces of varying levels rising from the valley floors along the streams between elevations of 4,000 to 6,000 feet. Eroded clay and shale hills with irregular ridges and projecting buttes present a "badlands" appearance in parts of the basin.

The Little Bighorn Basin is separated from the Bighorn Basin by the Bighorn Mountains. It drains a small portion of Wyoming. The basin is bordered on the east in Montana by the Rosebud Mountains. The Little Bighorn joins the Bighorn at the town of Hardin.

b. Activities Influencing Water Quality

The area is used largely for agricultural purposes. The largest combined category of employment is, however: in "primary services" with agriculture, forestry, sport fisheries, mining, and construction next in importance. Ranching and irrigated agriculture (hay, alfalfa) predominate in the lower reaches.

c. Water Quality

Water quality in the Bighorn Basin, particularly nearer the headwaters, is generally good. Water quality data available for this basin consist of nine mainstream monitoring stations and one Little Bighorn station. A short summary of several selected water quality parameters is presented in Table I-B.1-1.

The major source of pollution appears to be agriculture. There are several municipal discharges, both from sewage treatment plants and water treatment plants. In addition, there are two sugar beet refineries discharging to the Bighorn. One is in Worland and one is in Lovell.

Table I-B.1-1. Water quality data summary from selected stations in the Bighorn River Basin.

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Dissolved Metals								Total hardness mg/l
											Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	
Location and STORET No. At Thermopolis, Wyo. 06259500																			
No. of samples	15	8	10	19	18	2	-	1	10	9	-	-	-	5	-	-	5	-	11
Maximum value	19.5	14.3	3.7	9.0	1800	541	-	0.00	2.40	0.30	-	-	-	1000	-	-	90.0	-	268
Minimum value	4.5	9.4	0.8	7.7	1030	471	-	0.00	0.00	0.01	-	-	-	200	-	-	70.0	-	198
Mean value	10.5	12.0	2.1	8.5	1325	506	-	0.00	0.41	0.06	-	-	-	540	-	-	80.0	-	229
Period of Record	69-70	69-70	69-70	69-70	69-70	70	-	69	69-70	69-70	-	-	-	69-70	-	-	69-70	-	69-70
Location and STORET No. At Lucerne, Wyo. 06264700																			
No. of samples	67	-	-	78	61	61	-	9 4/	-	-	-	-	-	77	-	-	77	-	78
Maximum value	23.0	-	-	8.6	12500	657	-	0.14	-	-	-	-	-	1100	-	-	220.0	-	316
Minimum value	0.0	-	-	7.3	620	268	-	0.00	-	-	-	-	-	200	-	-	30.0	-	140
Mean value	11.2	-	-	8.0	1829	464	-	0.05	-	-	-	-	-	476	-	-	76.6	-	235
Period of Record	66-73	-	-	66-73	66-73	67-73	-	67-68	-	-	-	-	-	66-73	-	-	66-73	-	66-73
Location and STORET No. At Neiber, Wyo. 06267050																			
No. of samples	45	-	-	52	31	26	-	9 4/	-	-	-	-	-	52	-	-	52	-	52
Maximum value	23.3	-	-	8.4	13100	588	-	0.14	-	-	-	-	-	1000	-	-	210.0	-	553
Minimum value	8.0	-	-	7.4	581	446	-	0.00	-	-	-	-	-	300	-	-	0.0	-	149
Mean value	10.7	-	-	8.0	1679	521	-	0.05	-	-	-	-	-	469	-	-	87.1	-	260
Period of Record	65-69	-	-	65-69	65-69	67-69	-	67-68	-	-	-	-	-	65-69	-	-	65-69	-	65-69

Table I-B.1-1 (contin.).

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Dissolved Metals								Total hardness mg/l
											Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	
Location and STORET No. At Worland, Wyo. 06268600																			
No. of samples	64	-	-	143	162	78	26	38	-	-	-	-	-	143	-	-	148	-	144
Maximum value	26.0	-	-	8.6	12340	767	70200	0.75	-	-	-	-	-	1100	-	-	1800	-	427
Minimum value	0.0	-	-	7.1	58	297	254	0.00	-	-	-	-	-	100	-	-	0.1	-	150
Mean value	12.1	-	-	7.9	1716	570	20360	0.16	-	-	-	-	-	497	-	-	88.0	-	267
Period of Record	64-73	-	-	64-73	64-73	67-73	65-68	67-69	-	-	-	-	-	64-73	-	-	64-73	-	64-73
Location and STORET No. Near Manderson, Wyo. 06269000																			
No. of samples	8	-	-	10	12	5	-	-	-	-	-	-	-	10	-	-	11	-	12
Maximum value	23.0	-	-	8.2	2020	833	-	-	-	-	-	-	-	1400	-	-	150.0	-	354
Minimum value	0.0	-	-	7.6	280	558	-	-	-	-	-	-	-	500	-	-	90.0	-	250
Mean value	6.9	-	-	7.9	1048	660	-	-	-	-	-	-	-	650	-	-	111.8	-	311
Period of Record	66-71	-	-	66-71	66-71	68-71	-	-	-	-	-	-	-	66-71	-	-	66-71	-	66-71
Location and STORET No. At Kane, Wyo. 06279500																			
No. of samples	99	14	10	385	457	85	53	53 [4]	6	6	7	7	-	339	-	3	346	6	384
Maximum value	25.5	13.5	4.4	8.6	20200	924	28900	1.33	0.20	0.20	16.0	5.0	-	2500	-	74.0	370.0	30.0	1450
Minimum value	0.0	6.1	1.3	6.8	370	276	12	0.02	0.00	0.02	2.0	1.0	-	200	-	20.0	0.0	0.0	119
Mean value	10.7	9.5	2.5	7.8	2590	597	4425	0.19	0.05	0.10	8.1	3.4	-	449	-	42.0	113.8	20.0	315
Period of Record	47-73	69-73	69-73	47-73	47-73	67-73	59-72	67-71	69-70	69-70	69-72	69-72	-	47-73	-	70-71	48-73	69-72	47-73

Table I-8.1-1 (contin.).

	Temp C	DO mg/l	BOD mg/l	ph units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Dissolved Metals								Total hardness mg/l
											Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	
Location and STORET No. **Near Hardin, Mont.** **06288500**																			
No. of samples	61	30	31	35	45	39 1/	-	15	32	33	1	1	-	8	-	-	-	1	28
Maximum value	21.0	15.0	3.2	8.7	8000	952	-	0.60	0.59	1.00	5.0	10.0	-	600	-	-	-	8.0	340
Minimum value	0.0	8.4	0.7	7.5	530	362	-	0.10	0.00	0.00	5.0	10.0	-	400	-	-	-	8.0	140
Mean value	8.3	11.4	1.7	8.0	4000	622	-	0.37	0.08	0.12	5.0	10.0	-	438	-	-	-	8.0	267
Period of Record	69-73	70-73	70-73	69-73	69-73	69-73	-	69-70	69-72	69-73	73	73	-	72-73	-	-	-	73	69-73
Location and STORET No. **At Hardin, Mont.** **(Net) USGS** **EPA-290104**																			
No. of samples	390	350	-	390	249	106 2/	-	-	157	47	16	16	-	14	2	10 3/	15	16	381
Maximum value	27.5	22.0	-	9.3	21800	1160	-	-	0.50	1.14	68.0	21.0	-	560	0.0	400.0	600.0	46.0	540
Minimum value	0	7.5	-	7.5	160	370	-	-	0.10	0.01	4.0	2.0	-	320	0.0	12.0	79.0	2.0	100
Mean value	8.8	11.4	-	8.5	3755	721	-	-	0.30	0.10	28.7	8.6	-	436	0.0	122.3	238.8	16.5	316
Period of Record	61-69	62-69	-	61-69	60-66	61-64	-	-	62-65	64-69	62-71	62-71	-	62-69	62-63	63-71	62-71	62-71	61-69
Location and STORET No. **At Bighorn, Mont.** **06294700**																			
No. of samples	81	-	-	275	343	32	47	11	-	-	-	-	-	70	-	-	57	-	275
Maximum value	27.2	-	-	8.5	23000	836	21100	0.50	-	-	-	-	-	700	-	-	270.0	-	643
Minimum value	0.0	-	-	7.0	612	471	42	0.01	-	-	-	-	-	200	-	-	30.0	-	169
Mean value	12.8	-	-	7.7	4249	608	4088	0.18	-	-	-	-	-	400	-	-	133.5	-	338
Period of Record	59-73	-	-	59-73	59-73	68-73	59-71	69-70	-	-	-	-	-	59-73	-	-	59-73	-	59-73

Table I-B.1-1 (contin.).

											Dissolved Metals								
	Temp C	DO mg/l	BOD mg/l	ph units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Little Bighorn near Hardin 06294000																			
No. of samples	39	-	-	88	123	87	9	33	-	-	-	-	-	88	-	-	46	-	84
Maximum value	24.5	-	-	8.4	2060	749	19600	0.30	-	-	-	-	-	700	-	-	151.0	-	390
Minimum value	0.0	-	-	7.4	101	251	384	0.00	-	-	-	-	-	100	-	-	9.0	-	200
Mean value	8.9	-	-	8.0	527	468	7772	0.03	-	-	-	-	-	220	-	-	98.3	-	294
Period of Record	69-73	-	-	69-73	69-73	69-73	71	69-70	-	-	-	-	-	69-73	-	-	69-73	-	69-73

pH

Measurements for pH have been made at one or more of the ten stations since 1947. Five stations are currently monitoring pH on a regular basis. Recently reported values (1969-73) are in close agreement with the period of record mean values for each station. The highest mean value for pH, 8.5, occurs at Thermopolis, Wyoming in the upper Bighorn River Basin, after which a generally downward trend was observed until near the confluence at Bighorn, Montana, which has an average pH of 7.7. The range of mean values in the basin varied from 8.5 to 7.1. No problems of extreme acidity or basicity are apparent in the Bighorn River at this time.

Dissolved Oxygen

The limited dissolved oxygen data available for the Bighorn River basin (a total of 52 separate analyses at only three stations since 1969) makes it difficult to draw conclusions concerning current or long-term dissolved oxygen concentrations. The mean dissolved oxygen concentrations range from 9.5 to 12.0 mg/l at the sampling sites. The high and low individual dissolved oxygen concentrations measured at the three sampling stations were 15.0 and 6.1 mg/l, respectively. On the basis of a cursory examination of these data, there does not appear to be a dissolved oxygen depletion problem in the Bighorn River Basin.

Total Dissolved Solids

The average TDS concentrations for the period 1967-73 indicate an an increasing trend as the Bighorn River flows toward the Yellowstone River (Table I-B.1-1). The upstream concentrations at Thermopolis, Wyoming averaged 506 mg/l, while the Bighorn, Montana, station near the mouth of the Bighorn River averaged 608 mg/l. Figure I-B.1-1 is used to illustrate the upward trend. The high TDS values for Manderson, Wyoming may not be completely representative since only five samples were recorded over the period 1968 to 1971.

Flow

The flow data available from the Bighorn River Basin shows an overall increase in flow in the downstream direction from 1325 cfs at Thermopolis, Wyoming to 4249 cfs at Bighorn, Montana. Figure I-B.1-1 illustrates the variability of this trend. Periodically, the Bighorn River flow decreases to less than 100 cfs (at Worland) during which time the TDS concentrations achieve their highest values.

High flows in the Bighorn River usually occur during the Spring runoff, reaching values as high as 23,000 cfs. The maximum flow of 2020 cfs at Manderson was obtained from only 12 measurements and may not represent the true maximum flow at that location.

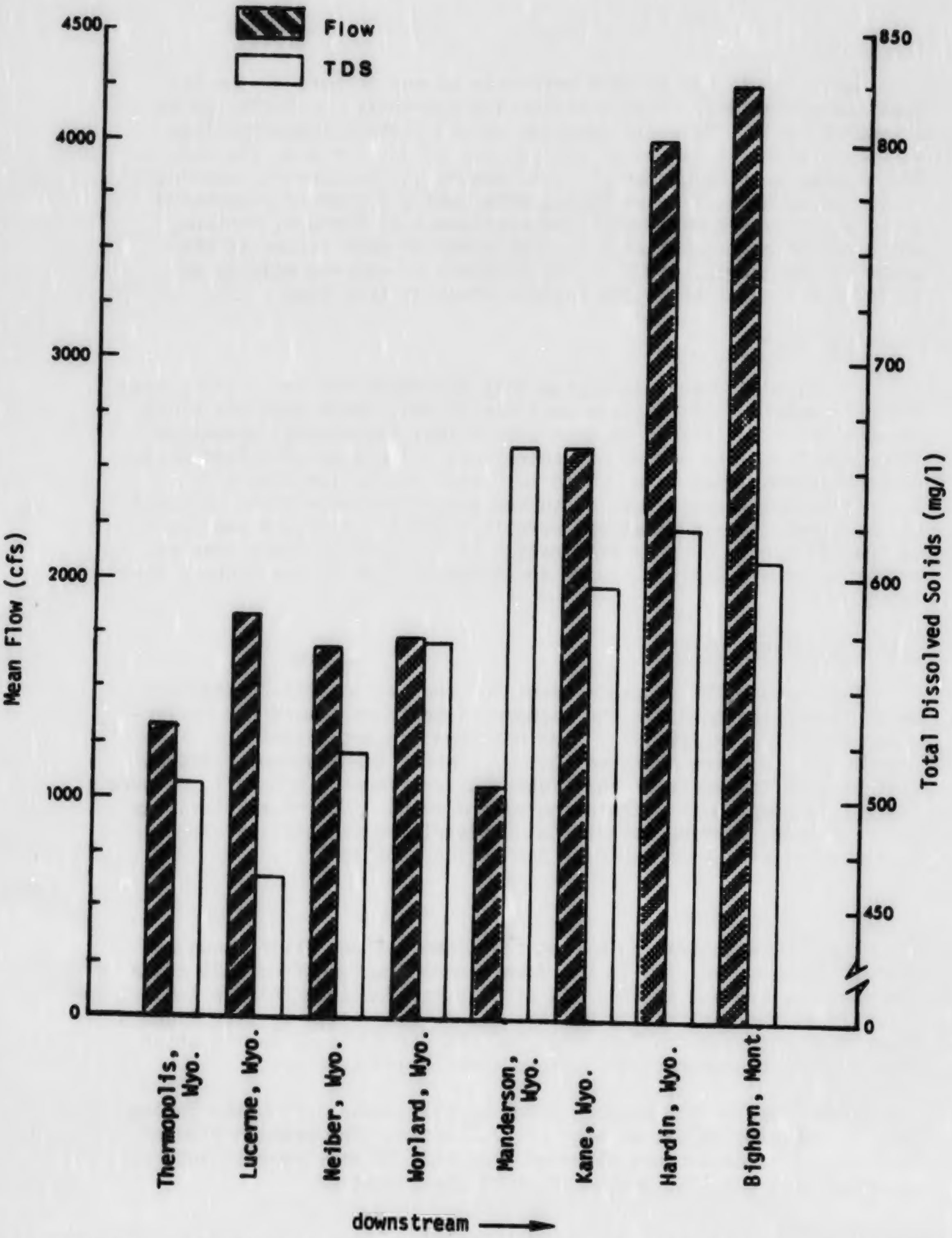

Fig. I-B.1-1 Mean flow and mean total dissolved solids for the period-of-record at selected sampling points on the Bighorn River.

Trace Metals

The trace metal data for the Bighorn River Basin are very incomplete and scattered throughout the period of record (1947-73). No mercury concentrations are recorded and only two values were recorded for selenium (both at 0.01 ug/l). Lead copper, and zinc concentrations are recorded at two locations, the mean concentration for all three metals being less than 30 ug/l. The highest metals concentration recorded was 68 ug/l of lead at Hardin, Montana. Aluminum was measured 10 times prior to 1971 at Hardin, and the average total aluminum concentration was 122.3 ug/l. Fluoride and boron were measured extensively at all sampling stations with mean values of about 475 and 125 ug/l, respectively. There does not appear to have been any significant problem caused by these trace metals on the water of the Bighorn River Basin.

Suspended Solids

The data for suspended solids concentrations in the Bighorn River Basin are limited and show tremendous variability. Analysis of the period of record data (1959-73) at the Kane, Wyoming station demonstrates the problems encountered in drawing generalized conclusions concerning suspended solids concentrations in the Bighorn River. Sampling for suspended solids was conducted during four different time periods (1960, 61, 64, 70-73) which resulted in the following respective suspended solids concentrations: 4933, 11469, 7880, and 473 mg/l. The highest individual concentration reported for the Kane station was 28900 mg/l and the lowest concentration was 12 mg/l. It is difficult to correlate suspended solids concentration with stream flow. The lower suspended solids concentrations, however, were reported during relatively low flow periods (less than 2000 cfs). A similar situation would likely be observed at Worland, Wyoming and Bighorn, Montana if an in-depth analysis of daily data were conducted. Mean concentrations at these two sampling locations were 20360 and 4088 mg/l, respectively.

Biochemical Oxygen Demand

A total of 51 analyses for BOD determination have been made on samples collected at three locations on the Bighorn River during the period 1969-73. The highest BOD concentration reported at any station was 4.4 mg/l at Kane, Wyoming, while the lowest concentration was 0.7 mg/l at Hardin, Montana. Mean values were 2.1, 2.5 and 1.7. On the basis of these data, the mean BOD concentration for the river was 2.1 mg/l. The reported BOD concentrations, on the basis of a cursory check of the daily data for the Kane, Wyoming sampling site, do not appear to be related to stream flow or time of year.

Nutrients

This report includes in the classification of "nutrients" the following parameters: total NO_3 as N, total NH_3 as N, and total PO_4

as P. A total of 175 analyses for total NO_3 were made at the eight sampling stations during 1967-71. About 360 analyses for dissolved NO_3 were made at Kane, Wyoming since 1947. The resulting values for dissolved NO_3 correspond closely with the total NO_3 values reported during the recent years at the same location. The mean concentrations of total NO_3 correspond closely with the total NO_3 values reported during the recent years at the same location. The mean concentrations of total NO_3 in the Bighorn River range from 0.16 mg/l at Worland, Wyoming to 0.37 mg/l near Hardin, Montana. High concentrations ranged from 0.50 mg/l at Bighorn to 1.33 mg/l at Kane.

Mean ammonia concentrations (as N) ranged from 0.41 mg/l at Thermopolis to 0.05 mg/l at Kane. These values are based on 48 reported values obtained at three sampling sites since 1969.

Total PO_4 concentrations were reported at three locations with the high values ranging from 0.20 mg/l at Kane, Wyoming, to 1.00 mg/l at Hardin, Montana. Mean values ranged from 0.06 mg/l at Thermopolis to 0.12 mg/l at Hardin. These results are also based on 48 samples collected since 1969. Similar results were reported at the Hardin, Montana station for the period 1962-69.

Temperature

The mean temperatures at the ten sampling sites on the Bighorn and Little Bighorn Rivers ranged from 6.9° to 13° C. Temperatures were often as low as 0° C, while high temperatures often reached 25°-27° C.

d. The Fishery

The fishing in the Bighorn Basin in Wyoming currently supports about 25,000 fishermen days,[1] an estimated one-third of capacity. The Bighorn River fishery is divided into two distinct sections by the Yellowtail Reservoir, which is roughly on the Montana-Wyoming state line.

The upper reaches of the Bighorn River, in Wyoming, consist of a small stretch of Class One fishing, some Class Two fishing, and considerable Class Three fishing. The Wyoming Game and Fish Department describes a Class One fishery as a trout fishery of national significance; a Class Two fishery as a trout fishery of state importance; and a Class Three fishery as a trout fishery of regional importance.

Productivity of fish in the upper reaches is good. The upper area is one of considerable natural beauty, although in much of the area development by man has reduced the wilderness significance. The downstream reaches in Wyoming deteriorate in quality due to agricultural stress. Irrigation demands cause low flows and silt laden return flows cause problems that reduce the fishery potential. Major fish present in Wyoming include rainbow trout, brown trout, sauger, walleye, northern pike, yellow perch, channel catfish, burbot and suckers.

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[1] Water and Related Land Resources at the Bighorn River Basin, Wyoming, Wyoming Water Planning Program Report #11, October 1972, State Engineer's Office, Cheyenne, Wyoming.

Below the Yellowtail afterbay dam in Montana an excellent cold water fishery exists for at least twelve miles to St. Xavier. Rainbow trout are abundant and brown trout and cutthroat trout are common. Walleye, sauger, northern pike, channel catfish, carp and suckers are also found. There is a seasonal migration of goldeye each year.

Below St. Xavier to near Hardin a transition from a cold water fishery to a warm water fishery occurs. There is increased agricultural stress applied to the stream. While there are still some trout, the fishery is dominated by such species as chub, carp, suckers, catfish, sauger, and goldeye.

Below Hardin a warm water fishery exists. While there are still some brown trout, the quantity is small. The stream is high in nutrients (throughout the basin) from agricultural runoff, and dissolved and suspended solids. Goldeye, catfish, carp, suckers, minnows, and a few paddlefish can be found. (There have been a few paddlefish seen in the lower reaches near the confluence with the Yellowstone.)

I-B.2 Tongue River Basin

a. The Basin

The Tongue River drainage contains about 1314 square miles, of which 488 square miles are in National Forest land. The topography ranges from high mountain peaks (11,000 ft) to relatively dry sage brush flats and grass land (3,463 ft). The topography of the head waters is typical mountain forest land of lodgepole pine, timber pine, Engleman spruce, Douglas fir, alpine fir, and aspen. Open grassy parks are numerous in the mountain areas. Stream side cover usually consists of willow and other low brush, as well as forest trees and grass.

None of the tributary streams in the Tongue drainage originate from lakes. The vast majority of the streams head in areas of granite rock and flow over granite formations. Limestone formations occur in the North and South Tongue River drainages. In the South Tongue drainage, tributary streams which drain from the east are of poor water quality (with reference to stream productivity) while those which drain from the west are of good water quality.

The Tongue River Reservoir, located just over the border in Montana, changes the character of the stream tremendously. The regulated flow provides a more uniform flow and keeps the temperature somewhat lower.

b. Activities Influencing Water Quality

The upland forest lands are used for recreation, grazing of sheep, cattle and big game, and timber production. Mining claims exist, but actual mining of precious metals has not occurred for many years. Irrigation demands and return of this water to the streams cause fluctuating water levels and increased silting as one proceeds downstream.

Land use downstream of the Tongue Reservoir remains largely agricultural. The "higher" low flows allowed by the Tongue River Reservoir have improved fishing habitat during historically low flow periods.

With the exception of agricultural return flows, the majority of discharges to the Tongue River are from municipalities. There is a small power plant discharging near Acme and a concrete company near Sheridan. Agricultural pressure is mainly from irrigation demand, consumptive use return flow, and feedlot operations. There are two coal mines presently discharging into the Tongue River. One is in Wyoming near Sheridan, and one is in Montana near Decker. Operations of one of these mines, located in close proximity to perennial streams, have caused some sediment problems in the adjacent waters.

c. Water Quality

Existing water quality data are summarized in Table I-B.2-1. Data are again relatively scarce. The data reported are from three active stations on the mainstream of the Tongue River in Wyoming and Montana and one active station in Goose Creek near Sheridan, Wyoming.

pH

Measurements for pH have been made at two of the four locations since 1959. The mean pH value for the period-of-record at each location is quite representative of the recent pH values recorded for the Tongue River since 1970. The mean pH value was equal to 8.0 ± 0.1 at the three mainstem sampling sites and 7.7 in Goose Creek. The maximum pH recorded (8.8) occurred at Miles City, Montana, in December, 1967, while the minimum reported value (6.7) occurred in Goose Creek downstream from Sheridan in June, 1970. On the basis of the existing data, there has been no pH problem in the Tongue River basin.

Dissolved Oxygen

There are no dissolved oxygen data reported for the four sampling sites in the Tongue River basin.

Total Dissolved Solids

Average TDS values for the Tongue River increase steadily in the downstream direction from Dayton, Wyoming (133 mg/l) to Miles City, Montana (560 mg/l) near the confluence with the Yellowstone River. Goose Creek had a mean concentration of 408 mg/l. Figure I-B.2-1 illustrates the increasing trend for the period-of-record (1967-73). No significant differences are apparent between the pre-1970 data and post-1970 data at any sampling location. The maximum TDS value (816 mg/l) occurred at Miles City, Montana in December, 1969, while the minimum value (72 mg/l) occurred in May, 1972 at Dayton, Wyoming.

Flow

Average flows in the Tongue River increased from 199 cfs at Dayton, Wyoming to 594 cfs at Miles City, Montana. Spring runoff flows exceed these average values considerably, ranging from highs of 1270 to 3149 cfs at the two stations. Flows as low as 16 cfs have been reported at Miles City, with correspondingly high values for TDS concentrations. Goose Creek flows were similar for the period 1959-1973.

Trace Metals

Boron and fluoride are the only two trace metals for which data were available. A summary of these data indicated that boron concentrations ranged from 0 to 1250 ug/l at the four stations, with mean

Table I-B.2-1. Water quality data summary from selected stations in the Tongue River Basin.

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Dissolved Metals Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Near Dayton, Wyoming 06298000																			
No. of samples	82	-	-	85	75	73	-	86a/	-	-	-	-	-	85	-	-	87	-	85
Maximum value	20.6	-	-	8.5	1270	168	-	0.29	-	-	-	-	-	400	-	-	140.0	-	172
Minimum value	0.0	-	-	7.1	37	72	-	0.00	-	-	-	-	-	0	-	-	0.0	-	60
Mean value	6.1	-	-	8.0	199	133	-	0.09	-	-	-	-	-	159	-	-	24.2	-	125
Period of Record	66-73	-	-	66-73	66-73	67-73	-	66-73	-	-	-	-	-	66-73	-	-	66-73	-	66-73
Location and STORET No. At St. Line near Decker, Montana 06306300																			
No. of samples	42	-	-	162	187	116	-	172 a/	-	-	-	-	-	165	-	-	176	-	163
Maximum value	27.2	-	-	8.6	3280	732	-	1.33	-	-	-	-	-	600	-	-	380	-	580
Minimum value	0.0	-	-	7.0	32	145	-	0.00	-	-	-	-	-	<200	-	-	0.0	-	108
Mean value	10.0	-	-	8.1	547	449	-	0.20	-	-	-	-	-	391	-	-	170.4	-	321
Period of Record	66-73	-	-	65-73	65-73	67-73	-	65-73	-	-	-	-	-	65-73	-	-	65-73	-	65-73
Location and STORET No. At Miles City, Montana 06308500																			
No. of samples	35	-	-	236	260	34	-	11	-	-	-	-	-	62	-	-	50	-	236
Maximum value	29.4	-	-	8.8	4139	816	-	0.10	-	-	-	-	-	800	-	-	1250.0	-	568
Minimum value	0.0	-	-	6.9	16	262	-	0.01	-	-	-	-	-	200	-	-	10.0	-	104
Mean value	10.5	-	-	7.9	594	560	-	0.04	-	-	-	-	-	361	-	-	137.3	-	324
Period of Record	66-73	-	-	59-73	59-73	68-73	-	69-70	-	-	-	-	-	62-73	-	-	62-73	-	59-73

Table I-8.2-1 (contin.).

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Dissolved Metals								Total hardness mg/l
											Pb μg/l	Cu μg/l	Hg μg/l	F μg/l	Se μg/l	Al μg/l	B μg/l	Zn μg/l	
Location and STORET No. Goose Creek below Sheridan, Wyoming 06305500																			
No. of samples	61	-	-	113	99	62	13	9 b/	-	-	-	-	-	113	-	-	112	-	113
Maximum value	27.0	-	-	8.5	1360	708	244	1.87	-	-	-	-	-	600	-	-	330.0	-	543
Minimum value	0.0	-	-	6.7	12	94	6	0.07	-	-	-	-	-	0	-	-	10.0	-	65
Mean value	9.6	-	-	7.7	180	408	48	0.60	-	-	-	-	-	400	-	-	112.1	-	321
Period of Record	64-73	-	-	59-73	59-73	67-73	71-72	67-72	-	-	-	-	-	59-73	-	-	59-73	-	59-73

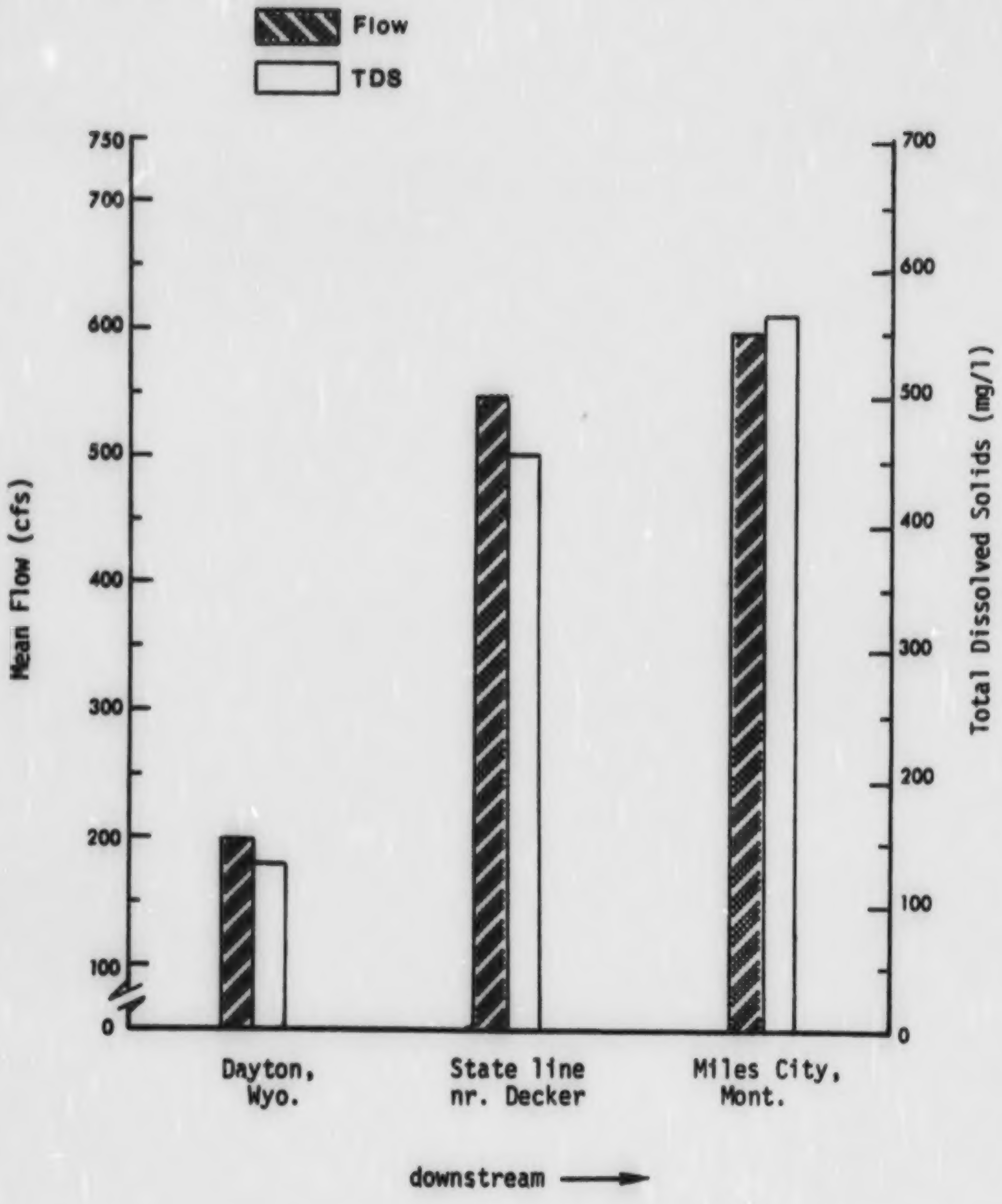

Fig. I-B.2-1 Mean flow and mean total dissolved solids for the period-of-record at selected sampling points on the Tongue River.

values (in downstream order on the mainstem of the Tongue River) of 24, 170, and 137 ug/l, respectively. Fluoride concentrations exhibited a range of 0 to 800 ug/l, and mean concentrations (in downstream order on the mainstem) of 159, 391, and 361 ug/l, respectively. Similar values were reported for Goose Creek.

Suspended Solids

There were no suspended solids data reported for the Tongue River basin sampling sites.

Biochemical Oxygen Demand

There were no biochemical oxygen demand data reported for the Tongue River sampling sites.

Nutrients

Nutrient information for the Tongue River Basin is limited to dissolved nitrate data only. A total of 258 measurements for dissolved nitrate were were made at Dayton and Decker on the mainstem Tongue, resulting in mean values of 0.09 and 0.20 mg/l as N, respectively. Maximum concentrations at the two locations were 0.29 and 1.33 mg/l as N, respectively. At the other mainstem location near Miles City, the mean total nitrate concentration was 0.04 mg/l as N and the maximum concentration was 0.10 mg/l as N based on an analysis of 11 samples. The Goose Creek sampling site exhibited a range of dissolved nitrate from 0.07 to 1.87 mg/l as N, with a mean concentration for nine samples of 0.60 mg/l as N. No attempt has been made to correlate dissolved nitrate values with total nitrate values, though under normal conditions a large difference should not exist.

There were no data reported for ammonia or phosphate concentrations.

Temperature

Average temperature in the waters of the Tongue River Basin ranged from 6.1° to 10.5°C, while the high values ranged from 20.6°C at Dayton, Wyoming (upstream station) to 29.4°C at Miles City, Montana near the confluence with the Yellowstone River.

d. The Fishery

The upper portions of the Tongue River are rated by the Wyoming Game and Fish Department as Class 2, or very good tr[illegible] waters of statewide importance. That Department rates the general esthetics of the area as outstanding. The rating of the upper river area is described as a stream of outstanding natural beauty of a unique type and possessing wilderness characteristics. The stream is usually clean and clear. The stream productivity is good, supporting a moderate fishery comprised of several species of salmonids. There is also a good diversity of species of aquatic insects. The angling in the upper reaches is primarily for brown trout and mountain whitefish. Planted rainbow trout are also important in the catch. Habitat conditions for trout spawning are generally favorable.

As the stream continues downstream near Dayton, Wyoming, increased development has occurred. Man-made additions, such as roads and farms, interfere with the wilderness qualities characteristic of upstream areas. Stream productivity ranges from good to poor. Brown trout and mountain whitefish remain the most abundant species. Wild rainbow contribute little to the fishing, but the stocking of "catchable" rainbows is important and a common management practice. Habitat conditions for trout spawning are generally good upstream from Ranchester. Downstream of Ranchester channel morphometry, diversions and the introduction of irrigation return water contribute to large silt deposits which limit trout reproduction.

Continuing downstream in Wyoming the Tongue flows through much more extensive and intensively developed farming areas. The fishing classification drops to 3, which is "important trout waters on a regional basis." Productivity decreases and more non-game fish are present. Dominant game fish include whitefish, brown trout, rainbow trout. Dominant non-game fish include carp, white sucker, redhorse, longnose and mountain suckers, flathead chubs, and longnose dace. Present fisheries management objectives are directed at habitat improvement. Near the state line the fishery has deteriorated to one that is basically incapable of sustaining substantial fishing pressure for desirable gamefish species. Productivity is very poor. The limiting variable for trout is water temperature[1] and possibly turbidity. Rock bass, crappie, and stonecats are predominant in the fish population.

Downstream of the Tongue River Irrigation Reservoir in Montana, to about Birney, the fishing is rated very good. As noted earlier, the fishery has been improved by increased Summer flows. Brown trout and rainbow trout are abundant. Smallmouth bass, walleye, northern pike, stonecat, rock bass and carp are also common. Downstream of Birney increased agricultural pressure contributes to the transition into a warm water fishery. Channel catfish become more plentiful. Stonecat, rock bass, northern pike, and some smallmouth bass represent the bulk of the game fish species and suckers, flathead minnow, white and black crappie, and carp are common non-game species.

Near Brandenbury, Montana a diversion structure is thought to block fish migration and condition to some extent the type of fishery between this diversion and the "T&Y" diversion. The stream is generally too warm for trout. Below the T&Y diversion (about 15 miles from the mouth), the fishery is comprised of fish species which seasonally move up the stream from the Yellowstone River. Paddlefish have been known to enter the Tongue. Carp, sauger, walleye, goldeye, flathead chubs, shorthead redhorse, stonecat, and longnose dace are common in the lower reach. It is thought that the area near the confluence of the Yellowstone and Tongue Rivers may be an important catfish spawning and nursery area.

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[1] A Fisheries Survey of the Lakes and Streams in the Tongue, River Drainage, Fisheries Technical Report #12, page 17, Wyoming Game and Fish Commission, 1958-1962.

I-B.3 Powder River Basin

a. The Basin

The Powder River drainage consists of the Little Powder River, Clear Creek, Crazy Woman Creek, and the Middle and North forks of the Powder as well as the main stem. The majority of the drainage is on private lands with most of the remainder on National Forest land. There is some BLM land in the drainage.

Topography in the drainage ranges from high mountain peaks (up to 13,170 ft.) to arid sagebrush flats and grasslands (down to 3,700 ft.). The headwaters of the drainage lie within typical forested lands of lodgepole pine, Engelmann spruce, Douglas fir, alpine fir and aspen. Open grassy parks are numerous in the mountain area. Stream-side cover usually consists of willow and bushy-type vegetation as well as forest trees and grass covered banks. Vegetative cover is good throughout most of the forest areas and erosion is held to a minimum.

Many of the tributary streams in the Clear Creek drainages arise from one or more mountain lakes. No lakes are present in the Crazy Woman, or the North and Middle forks of the Powder River drainages. The mountain lakes are surrounded by vast areas of granitic rock. Thus waters arising in the Clear Creek drainage are relatively "pure." Waters in the North and Middle forks of the Powder River Drainage are moderately alkaline due to the limestone formations in the southern Big Horn Mountains.

As the streams emerge from the mountains they begin to change rapidly. Irrigation demands greatly reduce the water flows. The return of irrigation water to the streams coupled with natural erosion of more sparsely vegetated areas adds large amounts of silt which removes spawning and food producing areas. The return of irrigation water into low stream flows tends to increase alkalinity which further modifies fish habitat.

b. Activities Influencing Water Quality

The forest lands are used primarily for recreation and the grazing of sheep, cattle and big game. Timber, primarily lodgepole pine and spruce, is harvested on a limited scale. The majority of the harvest is used for poles and native lumber. One gold mine is presently operated on the North Fork of the Powder River. There is no discharge from the mine.

The principal land use in the lower sections of the main streams and major tributaries is farming and ranching. The principal crops are alfalfa and some grains.

Significant discharges into the Powder River are from agricultural activities, municipalities, and oil field operations.

c. Water Quality

Current water quality information for the Powder River basin is based on data reported from four mainstem sampling sites, one Little Powder River site, and one South Fork Powder River site (Table I-B.3-1).

pH

All four mainstem Powder River sampling stations reported mean pH values for the period-of-record near between 7.8 and 8.0 units. Mean values for the Little Powder River near the Wyoming-Montana State line and for the South Fork Powder River near Kaycee, Wyoming were slightly lower at 7.7 and 7.6, respectively. The range of pH values at all stations was 8.5 to 6.6 units. There does not appear to have been any pH problem within the Powder River basin.

Dissolved Oxygen

Only two mainstem sampling stations, those farthest downstream, reported dissolved oxygen values. Five values were obtained in the period 1972-73 at Arvada, Wyoming, while 33 values were obtained during the period 1969-72 at Moorhead, Montana. The mean dissolved oxygen concentrations were 8.7 mg/l and 9.0 mg/l, respectively. Dissolved oxygen concentrations ranged from 4.5 to 12.8 mg/l at Arvada, while the range at Moorhead was 5.2 to 12.4 mg/l (one isolated dissolved oxygen concentration of 3.0 mg/l in February, 1972 was reported at Moorhead, but that may be an invalid analysis).

Total Dissolved Solids

All stations reported TDS concentrations, with individual periods-of-record varying from only 1967-68 at Sussex, Wyoming to 1949-73 on the South Fork of the Powder River near Kaycee, Wyoming. In general, the two tributary stations (S. Fork near Kaycee and Little Powder near State line) reported higher mean concentrations of TDS than did the two mainstem sampling stations. Tributary mean concentrations were 2140 and 2496 mg/l, respectively, while mainstem mean concentrations were (in downstream order) 872, 1452, 1826, and 1552 mg/l, respectively. Differences in the period of record may account for some differences in the concentrations. Maximum TDS concentrations ranged from 2060 mg/l near Kaycee to 4480 mg/l at Arvada, both of which are mainstream stations. Minimum concentrations measured ranged from 252 mg/l in the mainstem Powder River near Kaycee, to 1400 mg/l in the South Fork Powder River near Kaycee. Highest TDS concentrations were consistently observed during the lowest flow periods. The mean TDS concentrations in the Powder River basin averaged about three to four times greater than in either the Bighorn or the Tongue River basins.

Table 1-8.3-1. Water quality data summary from selected stations in the Powder River Basin.

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO3 as N mg/l	NH3 as N mg/l	T-PO4 as P mg/l	Dissolved Metals Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Powder River near Kaycee, Wyoming 06312500																			
No. of samples	51	-	-	134	126	64	-	7 4/	-	-	-	-	-	110	-	-	116	-	134
Maximum value	26.0	-	-	8.5	920	2060	-	.41	-	-	-	-	-	4000	-	-	350.0	-	1420
Minimum value	0.0	-	-	7.1	0.1	252	-	0.0	-	-	-	-	-	100	-	-	30.0	-	170
Mean value	11.4	-	-	7.8	128	872	-	.20	-	-	-	-	-	500	-	-	131.1	-	452
Period of Record	68-73	-	-	46-73	46-73	52-73	-	68-72	-	-	-	-	-	46-73	-	-	49-73	-	46-73
Location and STORET No. Powder River at Sussex, Wyoming 06313500																			
No. of samples	26	-	-	30	13	18	1	8 4/	-	-	-	-	-	30	-	-	30	-	30
Maximum value	23.9	-	-	8.2	2150	2450	744.0	0.50	-	-	-	-	-	1400	-	-	1200.0	-	743
Minimum value	0.0	-	-	7.2	26	157	744.0	.02	-	-	-	-	-	400	-	-	100.0	-	285
Mean value	8.5	-	-	7.8	412	1452	744.0	.27	-	-	-	-	-	900	-	-	358.3	-	549
Period of Record	66-68	-	-	66-68	66-67	67-68	67	68	-	-	-	-	-	66-68	-	-	66-68	-	66-68
Location and STORET No. Powder River at Arvada, Wyoming 06317000																			
No. of samples	57	5	4	162	182	126	35	72 4/	-	-	2	2	-	149	-	-	137	2	161
Maximum value	27.0	12.8	2.6	8.5	8360	4480	109000	0.74	-	-	40.0	70.0	-	2700	-	-	1600.0	18.0	1850
Minimum value	0.0	4.5	1.2	6.6	2	725	272	0.00	-	-	11.0	18.0	-	300	-	-	0.3	12.0	320
Mean value	11.4	8.7	1.9	7.8	536	1826	23813	0.33	-	-	25.5	44.0	-	900	-	-	325.3	15.0	699
Period of Record	67-73	72-73	72-73	46-73	46-73	50-73	68-72	67-70	-	-	72-73	72-73	-	46-73	-	-	48-73	72-73	46-73

Table I-B.3-1 (contin.).

	Temp C	DO mg/l	BOD mg/l	ph units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Dissolved Metals								Total hardness mg/l
											Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	
Location and STORET No. Powder River at Moorhead, Montana 06324500																			
No. of samples	62	33	34	34	55	1/	-	-	31	30	9	9	7	10	7	-	6	8	31
Maximum value	28.5	12.4	10.0	8.5	4600	4080	-	-	0.61	3.20	5.0	30.0	0.9	2200	11.0	-	448.0	32.0	1220
Minimum value	0.0	5.2	0.6	7.4	8	676	-	-	0.00	0.0	0.0	0.0	0.0	0.0	0.0	-	241.0	0.0	0
Mean value	10.5	9.0	3.0	8.0	642	1552	-	-	0.09	0.54	1.0	10.4	0.2	500	3.7	-	274.8	16.0	615
Period of Record	69-72	69-72	69-72	69-72	69-72	69-72	-	-	69-72	69-72	69-72	69-72	70-72	69-72	70-72	-	69-72	69-72	69-72
Table																			
Location and STORET No. Little Powder River near Wyo.-Mont. State 06324985																			
No. of samples	3	-	-	5	5	5	-	-	-	-	-	-	-	5	-	-	7	-	5
Maximum value	15.5	-	-	8.0	55	4050	-	-	-	-	-	-	-	2100	-	-	260.0	-	1310
Minimum value	0.0	-	-	7.3	0.1	791	-	-	-	-	-	-	-	500	-	-	90.0	-	263
Mean value	10.2	-	-	7.7	17	2140	-	-	-	-	-	-	-	1200	-	-	168.6	-	691
Period of Record	69-70	-	-	69-70	69-70	69-70	-	-	-	-	-	-	-	69-70	-	-	69-70	-	69-70
Location and STORET No. So. Fork Powder River near Kaycee, Wyoming 06313000																			
No. of samples	40	-	-	104	101	104	-	115 8/	-	-	-	-	-	97	-	-	105	-	104
Maximum value	-	-	-	8.4	504	4410	-	12.6	-	-	-	-	-	4500	-	-	540.0	-	1630
Minimum value	0	-	-	-	0	1400	-	0	-	-	-	-	-	800	-	-	22.0	-	433
Mean value	15.5	-	-	7.6	60	2496	-	1.71	-	-	-	-	-	1571	-	-	305.2	-	1039
Period of Record	68-73	-	-	49-73	51-73	49-73	-	49-73	-	-	-	-	-	49-73	-	-	51-73	-	49-73

Flow

Mean flows for the period-of-record in the mainstem of the Powder River increased uniformly from upstream to downstream stations as follows: 128, 412, 536, and 642 cfs, respectively (Figure I-B.3-1). The Little Powder and the South Fork Powder monitoring stations reported mean flows of 17 and 60 cfs, respectively. Minimum flows at these two stations are often as low as zero, while in the mainstem of the Powder River minimum flows range from 0.1 to 28 cfs. Lowest flows were observed during the late summer months. Maximum reported flows in the Little Powder River, South Fork Powder, and the mainstem of the Powder River at Arvada, Wyoming, were 55, 504, and 8360 cfs, respectively.

Trace Metals

Very limited trace metal data were obtained from the STORET system. Only two stations in the Powder River basin reported dissolved lead, copper, and zinc concentrations, with a maximum of only nine analyses per station. Mean concentrations on the mainstem of the Powder River at Arvada were as follows: lead-26 ug/l, copper-44 ug/l, and zinc-15 ug/l. At Moorhead, Montana, the corresponding mean mainstem concentrations were: lead-1 ug/l, copper-10 ug/l, and zinc-16 ug/l (a general decrease). The highest concentration of any of these metals was 70 ug/l (dissolved) copper reported at Arvada. The Moorhead station also reported seven values for dissolved mercury and selenium during 1970-72, mean concentrations being 0.2 and 3.7 ug/l, respectively. Two other metals were measured frequently at all locations--fluoride and boron. Mean fluoride concentrations ranged from 500 ug/l in the mainstem Powder near Kaycee to 1571 ug/l in the South Fork Powder near Kaycee. Maximum concentrations have been as high as 4500 ug/l near Kaycee in the South Fork. The mean fluoride concentrations range from about 660 in the mainstem to 1340 in the tributaries. The mean boron concentrations averaged approximately 275 ug/l for all stations. The highest boron concentration reported was 1600 ug/l at Arvada, Wyoming.

Suspended Solids

The only pertinent suspended solids data was reported from the Arvada, Wyoming station on the mainstem of the Powder River. Thirty-five measurements were made during the period 1968-72. The mean concentration was 23,813 mg/l. The maximum concentration was 109,000 mg/l, while the minimum was 272 mg/l. One other suspended solids measurement of 744 mg/l was made in 1967 at Sussex, Wyoming on the mainstem of the Powder. As expected, the highest suspended solids concentration occurred during periods of highest stream flow. Suspended solids concentrations as high as those reported at Arvada could cause significant problems for particular water usages, especially if concentrations persist near 20,000 mg/l.

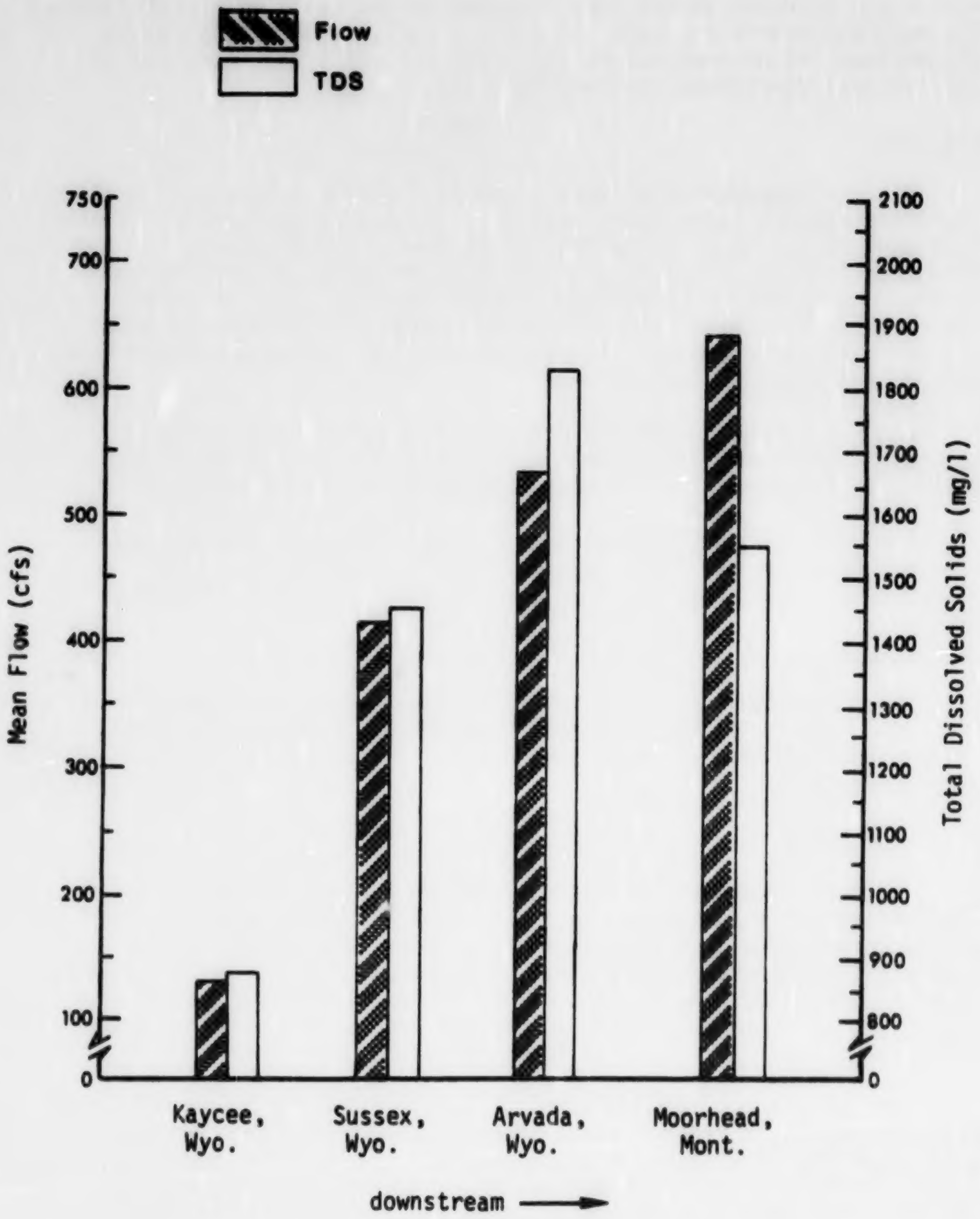

Fig. I-B.3-1 Mean flow and mean total dissolved solids for the period-of-record at selected sampling points on the Powder River.

Biochemical Oxygen Demand

A total of 38 analyses for BOD were reported during 1969-72 at Arvada and Moorhead on the lower reaches of the mainstem Powder River. The mean concentrations were 1.9 and 3.0 mg/l, respectively, while the maximum and minimum values (10.0 and 0.6 mg/l) both occurred at the furthest downstream station, Moorhead.

Nutrients

Nitrate concentrations were reported from three mainstem sampling locations and one South Fork location. The mean concentration is about 0.26 mg/l (total as N). The South Fork mean concentration of 1.71 mg/l dissolved nitrate (as N) is greater than the mainstem mean and the maximum concentration of 0.74 mg/l total nitrate (as N) reported at the mainstem locations. No correlation between dissolved and total nitrate has been attempted, but again the dissolved on the South Fork exceeds the total on the mainstem.

Ammonia nitrogen was measured at only the Moorhead, Montana mainstem location. Thirty-one analyses resulted in a maximum concentration of 0.6 mg/l and a mean concentration of 0.1 mg/l (as N).

Phosphate concentrations were reported from only the Moorhead sampling location (31 times during 1969-72). The maximum total phosphate concentration was 3.2 mg/l and the mean was 0.5 mg/l (as P).

Temperature

The temperatures in the mainstem of the Powder River ranged from 0° C to a high of 28.5° C reported at Moorhead, Montana near the Yellowstone confluence. Mean temperatures are generally in the 8-12° C range.

d. The Fishery

The main Powder River does not contain a significant fishery. Flow variations are extreme ranging from high turbid runoff in the spring to essentially a dry stream bed in the late summer months. Productivity compared to the other main tributaries to the Yellowstone River is poor and in many areas cannot sustain a fishery. However, the river may be important for a spawning and nursery area in good water years (migratory species from the Yellowstone River).

Limited channel catfish populations are found in the Powder River below the mouth of Clear Creek. Sauger probably inhabit the lower portion of the river since a small population exists in lower Clear Creek. Stonecats and black bullheads are the only other game fish present. Non-game species include flathead chubs, carp, goldeye, northern redhorse, white sucker, longnose sucker, mountain sucker, flathead minnows, and longnose dace.

In the lower portions of the Powder River in Montana, goldeye, flathead chub, and sturgeon chub are more common. Between Moorhead and Mizpah stonecat can be found. Carp, suckers, and channel catfish are the most prevalent.

Clear Creek forms at the confluence of the North and Middle Forks of Clear Creek on Forest Service land and flows about 79 miles before it enters the Powder River. From a point five miles downstream of Buffalo to its mouth, the flow in Clear Creek varies from sluggish to rapid. Habitat is generally unsuitable for trout due to lack of shelter, high water temperatures, and silt conditions.

However, downstream of Kendrick Dam (a barrier to fish migration), Clear Creek contains a fair population of channel catfish and a small number of sauger. Bullhead, stonecat, and rock bass comprise the majority of game fish. Non-game fish are much more abundant and include carp, northern redhorse, white sucker, longnose sucker, mountain sucker, goldeye, flathead chub, longnose dace, creek chub and flathead minnow.

Clear Creek does contain good rainbow trout and brown trout populations from the five-mile bridge downstream of Buffalo to the junction of the North and Middle Forks. The velocity is adequate and general habitat conditions are more favorable for trout. Upstream of the old Buffalo City Dam the stream is not influenced by irrigation diversions and rainbow trout are abundant. The present Clear Creek fishery in the upper reaches is self-sustaining as productivity is fair to good. Present management practices in the upper reaches include starting subrotatable trout and habitat improvement.

Crazy Woman Creek proper can be classed as intermittent below the bridge crossing on the "Nine-Mile Road" at the Smith Brothers Ranch. More than 50 miles of the lower stream from the mouth to the "Nine-Mile Road" is unsuitable for any type of game fish. A few carp, white suckers, plains flathead chubs, and goldeye inhabit the isolated pools. Since the substrate is comprised principally of silt, sand, and fine gravel, inverterbrate production is poor and food sources for fish limited. Normal summer turbidities prohibit the growth of rooted aquatic vegetation.

From the "Nine-Mile Road" crossing upstream to the forks, conditions in Crazy Woman Creek improve slightly. Siltation is less and permanently flowing water is available. Small populations of brown trout and stonecat inhabit the area. Non-game species include carp, white sucker, goldeye, plains flathead chub, and flathead minnow. Bottom fauna production is extremely low. Spawning areas for trout are essentially nonexistent.

The Little Powder River is not considered to have a good fishery. Sufficient water to support fish is present from the headwater to at least the MT-WY state line. However, flows are small and habitat limited, thereby restricting the game fish population. Introduced brook trout and rainbow trout survive in about 1 mile of the upper headwaters. Some sections downstream are periodically dewatered with fish habitat confined to the large and deeper holes in the stream bed. Summer water temperatures restrict trout in all but the short section influenced by headwater springs. The lower section contains channel catfish, black bullhead, and green sunfish. Other fish present include river carp sucker, white sucker, mountain sucker, flathead chub, flathead minnow and longnose dace.

The Middle Fork of the Powder River heads on the south end of the Big Horn Mountains at an elevation of 8100 feet. The lower limit of trout habitat is near the mouth of the Red Fork at approximately 4800 feet. Below this point stonecat are the only game fish. Fish populations near the mouth of the Middle Fork and at Kaycee are primarily comprised of non-game fish species, including white sucker, longnose sucker, mountain sucker, longnose dace, and plains flathead chub. Large quantities of silt from irrigation return are introduced in this section and turbidity is normally high. Summer temperatures are restrictive to trout.

Silty conditions caused by the inflow of Beaver Creek suppress trout populations between the mouth of Red Fork and the mouth of Beaver Creek. Conditions for trout improve about the mouth of Beaver Creek, but spawning conditions remain limited. Brown trout are the most abundant game fish downstream of Outlaw Canyon.

Approximately 12 miles of the Middle Fork through Outlaw Canyon is inaccessible except by foot. Consequently, there are no irrigation diversions or silt carrying irrigation return flows. Throughout Outlaw Canyon the Middle Fork is an excellent trout stream. Upstream of Outlaw Canyon fish populations consist mainly of brook trout with some rainbow trout.

The North Fork of Powder River heads under Powder River Pass, between the Hazelton Peaks and the main crest of the Big Horn Mountains. The lower limit for trout on the North Fork is near the Mayoworth School (elevation 5000 ft.). Downstream of Mayoworth, irrigation demands lower the stream flow and summer water temperatures become extreme.

In the lower portions of the North Fork the only game fish is stonecat. Mountain sucker, white sucker, flathead chub, and longnose dace are common. Above Mayoworth brown trout and planted rainbow trout are common. The fish population at the mouth of the North Fork Canyon is about two-thirds brown trout and one-third rainbow trout. The fish population at the upper end of the canyon is excellent. Rainbow trout dominate. The high production of bottom fauna water quality and habitat conditions are excellent for fish reproduction.

I-B.4 Yellowstone River (Mainstem in MT.)

a. The Basin

The Yellowstone Basin, situated in southeastern Montana and northern Wyoming, encompasses parts of two geographic regions: The Rocky Mountain province and the northwestern ranching area of the Great Plains province. Much of the mainstem of the Yellowstone River in Montana is characterized by a broad, terraced river calley. Above the terraced lands between the Missouri and Yellowstone River Valleys are smoothly rolling plains, eroded to different elevations.

b. Activities Influencing Water Quality

Two-thirds of the area in the basin is privately owned agricultural land, with the remainder in Indian and Federal ownership. In the upper reaches the scenic resources attract tourists from all parts of the nation. As a result, tourist trade and service activities in several communities are basic industries in these areas. Recreation, hunting, and fishing industries constitute a significant portion of the business activity of this subregion.

The Yellowstone River has been recognized for its recreational significance and potential by proclamation of the Montana State Game and Fish Department. By this proclamation the river was designed as a free flowing recreation waterway.

In the plains areas, surface conditions and climate combine to permit an agricultural economy of mixed dryland and irrigated farming and cattle ranching. Precipitation is too limited to permit widely diversified agriculture and only irrigated lands provide this base. The principal dryland products are livestock, hay, and wheat. Dry edible beans, sugar beets, hay and some vegetables are grown in the irrigated areas. Irrigation withdrawals and return flows tend to decrease the stream quality.

In addition to considerable agricultural pollution, the Yellowstone River also has several industrial and municipal discharges which contribute to reduced water quality. The largest number of industrial discharges are located in Billings. There are two oil refineries, a sugar beet refinery, and a power plant, in addition to a large sewage treatment plant. All discharge into the Yellowstone. There are many other municipal discharges along the river. Other major industrial discharges include power plants at Glendive and Sidney.

c. Water Quality

Water quality data on the Yellowstone River are somewhat more abundant than elsewhere. A summary of the existing water quality data based on five sampling stations, four of which are currently active, is given in Table I-B.4-1.

pH

All five sampling stations on the Yellowstone River exhibited similar pH values. The pH ranged from 6.8 at Billings and Custer to 8.9 at Sidney. Mean pH values for the period-of-record at all stations

Table I-8.4-1. Water quality data summary from selected stations in the Yellowstone River Basin.

	Temp C	DO mg/l	BOD mg/l	pH units	Flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ as N mg/l	T-PO$_4$ as P mg/l	Dissolved Metals								Total hardness mg/l
											Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	
Location and STORET No. Near Laurel, Montana 06214100																			
No. of samples	59	32	34	35	51	32 1/	-	17	32	31	9	9	7	10	8	-	8	8	32
Maximum value	22.0	13.1	5.2	8.6	41200	304	-	0.50	0.35	1.20	4.0	11.0	0.3	700	10.0	-	230.0	30.0	186
Minimum value	0.0	7.2	0.4	7.1	603	90	-	0.00	0.01	0.00	0.0	0.0	0.0	10	0.0	-	31.0	0.0	44
Mean value	7.6	10.2	1.6	7.7	7067	232	-	0.19	0.05	0.14	0.6	3.3	0.1	411	3.1	-	129.0	13.3	134
Period of Record	69-72	69-72	69-72	69-72	69-72	69-72	-	69-70	69-72	69-72	69-72	69-72	70-72	69-72	70-72	-	69-72	69-72	69-72
Location and STORET No. At Billings, Montana 06214500																			
No. of samples	62	-	-	192	246	34	1	16	18	4	4	4	-	116	3	2	110	4	192
Maximum value	21.0	-	-	8.6	48560	376	896	0.6	.44	0.07	14.0	42.0	-	1100	9.0	100.0	490.0	40.0	272
Minimum value	0.0	-	-	6.8	1330	78	896	0.0	0.00	0.04	0.0	0.0	-	100	6.0	96.0	9.0	0.0	28
Mean value	8.2	-	-	7.6	8439	230	896	0.1	.15	0.05	3.5	18.0	-	508	7.7	98.0	176.3	16.5	139
Period of Record	65-73	-	-	63-73	63-73	68-73	65	69-70	69-70	69-70	69-70	69-70	-	63-73	69-70	70-72	63-73	69-70	63-73
Location and STORET No. Yellowstone River at Custer, Montana 0621800																			
No. of samples	22	12	12	12	26	12 1/	-	11	12	12	1	1	-	1	-	-	1	1	12
Maximum value	23.0	13.6	8.1	8.4	27500	366	-	0.46	0.26	0.88	0	7.0	-	800	-	-	147.0	37.0	207
Minimum value	0.0	7.6	0.2	6.8	619	189	-	0.00	0.00	0.00	0	7.0	-	800	-	-	147.0	37.0	101
Mean value	7.9	10.4	2.8	7.9	7178	304	-	0.17	0.08	0.29	0	7.0	-	800	-	-	147.0	37.0	161
Period of Record	69-70	69-70	69-70	69-70	69-70	69-70	-	69-70	69-70	69-70	69	69	-	69	-	-	69	69	69-70

Table I-8.4-1 (contin.).

	Temp C	DO mg/1	BOD mg/1	pH units	Flow cfs	TDS mg/1	SS mg/1	T-NO$_3$ as N mg/1	NH$_3$ as N mg/1	T-PO$_4$ as P mg/1	Dissolved Metals Pb µg/1	Cu µg/1	Hg µg/1	F µg/1	Se µg/1	Al µg/1	B µg/1	Zn µg/1	Total hardness mg/1
Location and STORET No. Near Miles City, Montana 06296120																			
No. of samples	33	-	-	135	162	129	-	65	-	-	-	-	-	130	-	-	91	-	132
Maximum value	23.0	-	-	8.5	49900	624	-	0.50	-	-	-	-	-	900	-	-	226.0	-	290
Minimum value	0.0	-	-	6.9	3500	150	-	0.00	-	-	-	-	-	0	-	-	16.0	-	86
Mean value	8.6	-	-	7.7	14163	394	-	0.09	-	-	-	-	-	407	-	-	139.5	-	204
Period of Record	68-73	-	-	68-73	68-73	68-73	-	69-70	-	-	-	-	-	68-73	-	-	68-73	-	68-73
Location and STORET No. Near Sidney, Montana 06329500																			
No. of samples	97	18	18	311	375	37	24	23	25	41	4	4	-	83	-	4	79	4	293
Maximum value	24.4	12.6	3.3	8.9	65240	655	15500	0.69	0.26	2.70	0.0	10.0	-	800	-	200.0	260.0	0.0	403
Minimum value	0.0	7.4	0.9	6.9	1149	230	167	0.00	0.00	0.01	0.0	0.0	-	100	-	100.0	20.0	0.0	90
Mean value	11.3	9.8	1.8	7.8	14527	460	2308	0.20	0.06	0.32	0.0	2.5	-	449	-	150.0	146.4	0.0	245
Period of Record	65-73	70-73	70-73	59-73	59-73	68-73	65-72	69-70	69-72	69-73	66	66	-	59-73	-	66	59-72	66	59-73

was 7.8 ± 0.2 units. For the past four years (1970-73), the average pH has risen approximately 0.1 units per year at the Sidney location. The reason for this increase is unknown and therefore its accuracy is also unknown.

Dissolved Oxygen

Three of the five stations reported dissolved oxygen concentrations, and no values were less than 7.2 mg/l. Laurel, Custer, and Sidney reported mean concentrations of 10.2, 10.4, and 9.8 mg/l, respectively. The above values indicate that reduced dissolved oxygen concentrations are not presently a problem in the Yellowstone River.

Total Dissolved Solids

Mean TDS concentrations in the Yellowstone River increase uniformly from the Laurel-Billings upstream reach (230 mg/l) to Sidney, located near the confluence with the Missouri River (460 mg/l) (See Figure I-B.4-1). A part of the increase is contributed by tributary streams, particularly the Powder River (mean of 1552 mg/l at Moorhead) which enters upstream from Sidney. The maximum concentration of TDS was measured at Sidney (655 mg/l) while the minimum concentration was measured at Billings (78 mg/l). Minimum TDS values were consistently reported during periods of highest flows. The data examined indicate that current TDS concentrations are characteristic of the values exhibited in the past.

Flow

The Yellowstone exhibits a wide range of flows, varying from 603 cfs at Laurel to 65,240 cfs at Sidney. Spring runoffs produced the highest flows, often exceeding the mean flow by a factor of four to five. In downstream order, the mean flow values are: 7067, 8439, 7178, 14163, and 14527 cfs, respectively.

Trace Metals

Lead, copper, and zinc concentrations were reported at four sampling locations during the period 1966-72. With 18 analyses per parameter reported, the maximum concentrations were: Lead: 14 ug/l, copper: 42 ug/l and zinc: 40 ug/l, all measured at Billings. Mean concentrations for the River were 1.0 ug/l lead, 7.7 ug/l copper, and 16.7 ug/l zinc. Seven samples were collected at the Laurel station for mercury analysis during 1970-72, producing a mean reported concentration of 0.1 ug/l. Selenium analyses at Laurel and Billings gave mean concentrations of 3.1 and 7.7 ug/l, respectively. Dissolved aluminum was measured a total of six times at Billings and Sidney, with the mean concentrations 98 and 150 ug/l respectively and the maximum concentration 200 ug/l at Sidney. Fluoride and boron concentrations were measured extensively throughout the period-of-record. The highest mean concentrations were 508 ug/l fluoride and 176 ug/l boron, both at Billings, Montana.

Suspended Solids

Suspended solids data recorded at Sidney, Montana comprise the majority of available data. Twenty-four measurements between 1965-72 resulted in a mean suspended solids concentration of 2308 mg/l.

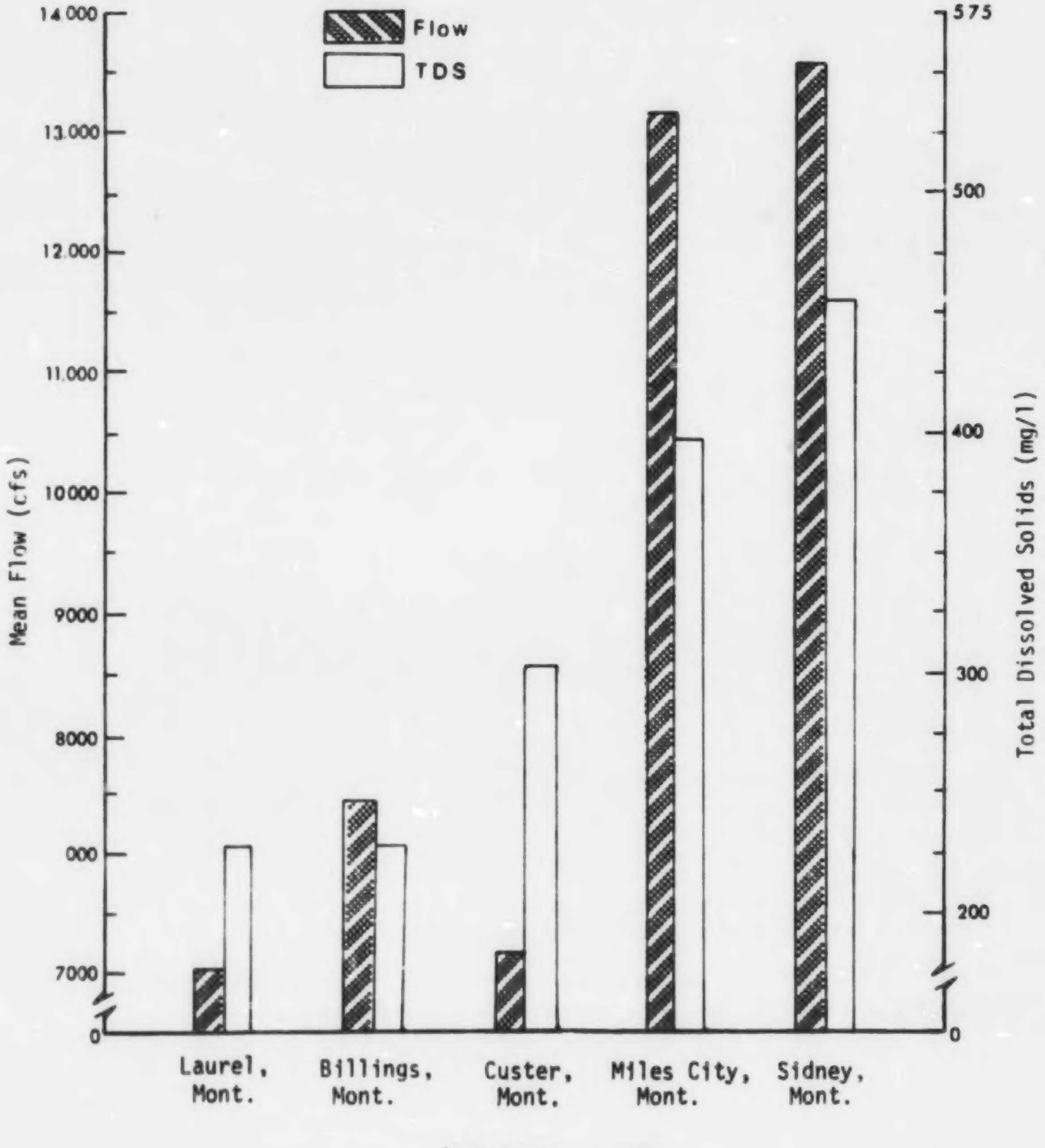

Fig. I-B.4-1 Mean flow and mean total dissolved solids for the period-of-record at selected sampling points on the Yellowstone River.

Biochemical Oxygen Demand

A total of 64 measurements for BOD were reported for the period-of-record (1969-73) in the STORET retrieval. The three sampling stations represented - Laurel, Custer, and Sidney - reported mean BOD values of 1.6, 2.8, and 1.8 mg/l, respectively. The highest concentration measured was 8.1 mg/l at Custer, Montana.

Nutrients

A considerable amount of nutrient data has been recorded for the Yellowstone River. Total nitrate as N concentrations were measured at all stations at some time during the period 1968-70, and mean concentrations ranged from 0.09 mg/l at Miles City to 0.2 mg/l downstream at Sidney. The mean for all stations was 0.15 mg/l. During the period 1969-73, seventy-seven measurements for ammonia were reported with mean concentrations ranging from 0.05 mg/l (as N) at Laurel to 0.15 mg/l at Billings. Total phosphate measurement for the 1969-73 period-of-record at four locations produced mean concentrations ranging from 0.05 mg/l (as P) at Billings to 0.29 mg/l at Custer with a mean for all stations of 0.20 mg/l.

Temperature

High temperatures in the Yellowstone River ranged from 21° C at Billings to 24.4° C at Sidney.

d. The Fishery

The opportunity for cold water fishing, mostly for trout, is abundant along the Yellowstone River. Substantial parts are of exceptionally high quality trout fisheries. The Montana Senate and House of Representatives introduced a joint resolution of public policy regarding maintenance of the unique natural functions of the Yellowstone River[1].

Despite the relative excellence of fishing waters (most particularly in the upper reaches of the streams), habitat problems exist. Serious sedimentation of streams is common, resulting both from natural soil characteristics and improper load use. Dewatering of streams has been and will continue to be a serious problem. Wastes from feedlots, other agricultural practices, industries, and municipalities also cause recognized problems for the fishery.

In the upper Yellowstone, above Livingston, the prominent game fish are mountain whitefish, rainbow trout, brown trout, and cutthroat trout. Other fish present include longnose sucker, white sucker, carp, and redhorse sucker. Important forage species include mottled sculpin and longnose dace. Rainbow trout and brown trout are the most important species in the stream as indicated by angler harvest. Cutthroat trout is second in importance. They are a sought after species, but are less abundant. Whitefish are third, and more important in the winter harvest. The upper Yellowstone water quality is excellent and is described as a cold, clear, free flowing stream. Aquatic insects of several orders (Trichoptera, Plecoptera, Ephemoptera, etc.) are present and constitute an important source of food for fish. Small fish, such as sculpin, and dace, are also important as food items for salmonids.

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[1] The Missouri River Basin Comprehensive Framework Study, Volume 7, page 97, December 1971

The fisheries management plan[1] for the upper Yellowstone calls for maintaining the stream in a free-flowing natural state with self-sustaining fish populations. Keeping man's influence on the river and its biological communities at a minimum is the biggest concern in fisheries management. Several changes in man's activities have improved the water quality recently: Mining activity has been reduced, there are better municipal and industrial treatment facilities, and pesticide use in some instances has decreased.

River temperatures increase downstream resulting in a change in the fish population. The predominant and most important sport fish above Laurel, Montana are mountain whitefish, brown trout, rainbow trout, and cutthroat trout, while downstream of Laurel the predominant and most important game fish are channel catfish, burbot, and sauger. Forage fish above Laurel are longnose sucker, white sucker, sculpin, and longnose dace, while below Laurel goldeye, white sucker, carp, longnose sucker, flathead chub, and shorthead redhorse suckers are common.

The water quality above Park City is excellent and from Park City to Laurel is basically good for fisheries. Important species of aquatic insects include stoneflies, mayflies, caddis flies, midge larvae, and diptera larvae. Below Laurel, the water quality is degraded and considered poor to Huntley, Montana and satisfactory below Huntley. The most important water quality influences affecting the fishery above Laurel are sediment and runoff from feedlots (as well as other agricultural effluents). Below Laurel sediment, sewage effluent, sugar plant effluent, and oil refinery effluent are most important. In the last 15 years there has been a substantial reduction in quantity and improvement in quality of industrial and municipal pollution as evidenced by an improvement of the taste of fish flesh and the reappearance of brown trout below Billings.

In the lower Yellowstone the most important game fish are sauger, channel catfish, burbot, and paddlefish. The most abundant fish is the goldeye. The stream is primarily a warm water fishery. The paddlefish is migratory and can be considered to be the most important species seasonally. In 1973 an estimated 2,500 anglers spent 10,150 hours

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1. Correspondence: Montana State Department of Fish & Game with James W. Shaw - January 15, 1974

snagging 4,670 paddlefish during May and June. The uniqueness of the species increases its importance.

Lack of background data on water quality and the life history of certain species in the lower Yellowstone makes it difficult to assess the most critical parameters necessary for perpetration of a specific species or sustaining the fishery. Flow is most important for paddlefish, since volume of water triggers, at least in part, the paddlefish migration up the Yellowstone River during the spring runoff. Other important parameters, such as temperature, dissolved solids and suspended solids, are also related to flow.

The paddlefish are presently being studied rather intensively by the Montana Department of Fish and Game. Present studies include general creel census data, collection of life history data (lengths, weights, sex, and jaws for age and growth), and tagging fish so that their movement can be followed to determine spawning areas and success.

Diversions of water for agricultural use, resulting in increased temperatures and channel alterations, are presently the most detrimental practices to the fishery and quality of fishing. Future industrial diversions reducing instream flow could affect the fishing substantially.

I-B.5 Little Missouri River Basin

a. The Basin

The Little Missouri River meanders approximately 560 miles dropping an average of 4.6 feet per mile from its source in Wyoming to Garrison Reservoir in North Dakota. It drains about 9,500 square miles of which more than one-half is located in North Dakota. The area drained is mostly of the Badlands type. Tributaries primarily to the west of the Little Missouri Divide flow through dark brown, hilly and steep land, with alkaline soils of the semi-arid grasslands type. The badlands complex is found throughout the river's course in North Dakota.

The annual precipitation averages about eleven inches. Most of this comes in the form of rain. Heavy snows have been recorded on the drainage but are not common. The stream flow fluctuates greatly reaching high levels in the spring and after heavy rains. Flows recorded at Medora, North Dakota have ranged from 0 to 65,000 cfs. High flows carry vast amounts of silt from surface erosion. Silts are deposited in the stream bed or carried to Garrison Reservoir. Silt deposits from four to twenty feet have been recorded in the lower 40 miles of the Little Missouri River behind Garrison Dam. The main channel contains no aquatic vegetation as a result of continuous shifting of bottom gravel, sand, and silt. Periods of no flow in the dry season leave a series of shallow disconnected pools. Deep pools are limited to sandstone layered areas where high water has scored out narrow troughs four to eight feet deep. Bank erosion is severe throughout most of the river's course, thereby restricting establishment of shoreline vegetation and adding to the silt load of the river.

b. Activities Influencing Water Quality

Much of the lands on both sides of the Little Missouri River are under public ownership. These holdings may extend back from the mainstems and include many of the smaller tributaries. Private lands are interspersed throughout much of the drainage but restricted primarily to the "bottomlands" and upland plateau areas away from the main channel. Private holdings in the bottoms act as headquarters for large cattle ranching operations. Most of the public lands throughout the basin are under lease for grazing. The private lands not grazed are cultivated for cattle forage and cereal grain production.

Intensive grazing and cultivation have reduced ground cover and increased the erosion potential. Over-use of the woody tributary draws by cattle has destroyed the understory reducing their value for retaining runoff water. Much of the woody cover that was present along the mainstem channel has been cleared or destroyed by grazing. The reduction of ground cover on the watershed has increased peak flows, shortened flow periods, increased the silt loads, and reduced percolation. Water quality changes and channel modification are directly reflected in the fish species changes observed the past 80 years.

c. Water Quality

The chemical nature of the waters found within the Little Missouri River Basin are considered to vary as much as the flow and the terrain through which it meanders. However, only one station was available for data analysis (Table I-B.5-1). The pH ranged from 6.8 to 8.8 at this Medora station over the period-of-record. A pH of 8.2 has been consistently recorded from the three impoundments on tributary streams that support fish life. A variation in conductivity of 460 to 2,150 micromhos is reported to exist seasonally. The mean TDS concentration at the Medora station was 1116 mg/l. Turbidity is a major factor affecting water quality and ultimately fish species composition. A measurement of 420 JTU's was taken from samples collected at Lost Bridge, Dunn County, North Dakota in the Spring of 1969.

Water temperatures vary and are subject to rapid change. The unprotected, shallow pools become very warm in the hot, dry summer months. Oxygen depletion occurs in some such areas. The range in DO at Medora was 2.9 to 15 mg/l. Aquatic populations are thus dependent upon the deeper pool areas in periods of low flow. Fish species distribution is totally dependent upon seasonal flow fluctuations for reintroduction by migration. BOD averaged 3.8 mg/l over the period-of-record.

d. The Fishery

The fisheries of the Little Missouri River have been investigated since 1893. Sampling has revealed a rather dramatic change in species composition and their distribution as noted earlier. The major factors effecting these changes have been increased silt loads, increased peak flows, and a decrease in the flow periods. Garrison Dam has also contributed greatly to the change in species composition serving as a source for upstream migration.

Fish collections in 1893 and 1926 indicated walleye, sauger, and white sucker were the most abundant larger species present. The northern plains minnow, flathead chub, and goldeye were also taken in large numbers. Catfish were reported only occasionally and northern pike not at all. Data from a pre-impoundment survey made in 1950 revealed a change in species distribution and abundance. Catfish and sauger were the only game fish collected. The white sucker, flathead chub, and river carpsucker were reported to be most abundant at all collection sites.

Intensive fish population sampling was carried out at 17 stations in 1971, 1972 and 1973. The survey was initiated to complete

Table I-B.5-1 Water quality data summary from station on the Little Missouri River

	Temp D	DO mg/1	BOD mg/1	pH units	flow cfs	TDS mg/1
Location and STORET No. Medora, N. D. 380022						
No. of samples	59	59	58	58	-	58[9]
Maximum value	22	15.0	12.2	8.8	-	2980
Minimum value	0	2.9	1.0	6.8	-	240
Mean value	9	9.9	3.8	7.9	-	1116
Period of Record	68-73	68-73	68-73	68-73	-	68-73

a life history study of the channel catfish in Garrison Reservoir. Seasonal movement was documented by capturing and tagging adult fish in the Little Missouri Arm of Garrison Reservoir. Tag returns from anglers verified mass movement of channel catfish up the Little Missouri River. Adult catfish were collected at 16 of the 17 stations. Natural reproduction was recorded at several of the collection sites. In addition to the tag-return data supplied by anglers, creel census information indicated a significant number of sauger and northern pike taken to creel. The flathead chub, sturgeon chub, and northern plains minnow were found to be seasonally abundant. Their abundance was directly proportional to seasonal flow periods. It is interesting to note the white sucker was not taken in three years of intensive study. The stonecat, found to be abundant in recent collections, was not taken in the 1950 pre-impoundment survey. The absence of the stonecat in this survey could be in part attributed to collection techniques. (Table I-B.5-2 is a list of fishes collected in the 1971 to 1973 survey.)

It was determined from the intensive investigations of 1971 to 1973 that the channel catfish population of Garrison Reservoir is directly dependent upon the Little Missouri River as a nursery area. The adults are able to penetrate the silt-laden water and move to spawning areas in peak flow periods. As waters recede, the adult channel catfish tend to remain in deeper pools throughout the summer. These same pools serve as nesting and nursery areas for channel catfish and forage species. Reproduction of forage species is also dependent upon flow periods and their seasonal fluctuations within the main channel and tributaries.

"Wet years" combined with high water tend to be more reproductive for major species found in the Little Missouri River. Alternating flow mechanically would have an effect on water temperatures. For maximum productivity flow must fluctuate seasonally. It would be advantageous however to maintain annual minimum flows because periods of no flow tend to negate benefits of fluctuation.

Table I-B.5-2

Little Missouri River Basin Fishery

Geographic Areas

1. Mainstem:	The main channel of the Little Missouri River from South Dakota to Lost Bridge on North Dakota Highway 22, Dunn County.
2. Tributaries:	Tributaries to the Little Missouri River in North Dakota including data from impoundments on these tributaries.

Relative Abundance in Each Geographic Area*

Species	1. Mainstem	2. Tributaries
Rainbow trout	absent	common
Goldeye	abundant	rare
Northern pike	common	rare
Carp	common	rare
Northern plains minnow	abundant	common
Sturgeon chub	abundant	common
Flathead chub	common	rare
Golden shiner	absent	common
Flathead minnow	absent	common
Longnose dace	common	rare
River carpsucker	abundant	rare
White sucker	absent	common
Northern redhorse	common	absent
Black bullhead	rare	rare
Channel catfish	abundant	rare
Flathead catfish	rare	absent
Stonecat	abundant	abundant
Brook stickleback	absent	rare
Bluegill	absent	common
Smallmouth bass	absent	rare
Largemouth bass	absent	rare
White crappie	rare	rare
Yellow perch	absent	common
Sauger	common	rare
Walleye	rare	rare

* Relative Abundance

Absent:	No specimens taken within the designated geographic areas.
Rare:	One specimen taken at one or more sampling stations.
Common:	One to ten specimens taken at one or more sampling stations.
Abundant:	More than ten specimens taken at more than one sampling station.

I-B.6 Knife River Basin

a. The Basin

The Knife River rises on the Little Missouri Divide to the west and the Missouri River Divide to the north. The mainstem and its tributaries meander over approximately 350 miles through rugged platteau lands, level bench lands and rolling to gently sloping prairies. The upper one-third of the drainage drops rapidly from the Little Missouri Divide. The lower main channel drops less and thus meanders through a wide valley created by erosion of the river and its tributaries. The valley is dominated by fertile bench lands. Hardwood tree stands with a brushy undercover are continuous along this portion of the main channel.

Soils vary greatly within the basin progressing from the clays of the hilly land soils of the badlands type to the dark brown loams in the valleys. Vegetation tends to be sparse in many areas. Most moisture comes in the form of rain in May and June. Snow cover rarely exceeds 12 inches within most of the basin. High flows in April and May may result from rapid thawing of accumulated snow cover.

b. Activities Influencing Water Quality

The first settlers in the Knife River Basin were primarily ranchers with headquarters located along the main channel. The Homestead Act brought row-crop farming to nearly all tillable lands. The drought of the 1930's and the Soil Bank Act of the late 1950's initiated a progressive change in land use. The recent demand for farm products has brought intensive row-crop cultivation and grazing to nearly all lands in the basin. Severe erosion is evident on both over-grazed and cultivated lands devoid of cover.

The entire Knife River Basin is underlain with lignite coal deposits. Past mining was limited primarily by demand and methodology. Pock marks from subsiding underground mine shafts are visible in many areas. Strip mining has now replaced underground mining.

c. Water Quality

Data on water quality in the Knife River are scarce. Data taken in 1972 and 1973 from impoundments within the basin indicate waters are high in nitrogen and phosphorus.

Silts high in nutrients are carried by the waterways in periods of heavy runoff. They are deposited in the many impoundments or carried to the Missouri River. Silts rapidly accumulate in all impoundments in the Knife River Basin resulting in high productivity. Because of these conditions, sport fishing waters are practically non-existant in the basin. Even the 1,300 acre Lake Ilo area is subject to winterkill annually because of siltation and eutrophication.

A summary of the water quality of the Knife River based on reported values from three monitoring stations is presented (Table I-B.6-1). The USGS station at Manning, North Dakota has been in operation only since 1972 and has reported only two measurements for any given parameter. A brief history of several selected water quality parameters for the period-of-record at each sampling site is presented in the following sections.

pH

Recorded pH values ranged from 6.6 to 8.6, both measurements recorded at the Golden Valley Monitoring site. Mean pH values ranged from 7.8 at Golden Valley to 8.0 at Manning. A seasonal variation in pH of 8.0 to 8.7 has been measured in two impoundments and in Spring Creek upstream of Lake Ilo in Dunn County.

Dissolved Oxygen

No dissolved oxygen concentrations have been measured at the three sampling sites on the Knife River.

Total Dissolved Solids

Average TDS ranged from 895 mg/l at Manning (only two measurements) to 1004 mg/l at both Golden Valley and Hazen, North Dakota. The maximum and minimum reported concentrations were 2700 mg/l and 114 mg/l, respectively, both values measured at the Golden Valley location. Other chemical analyses indicate that the alkalinity of selected waters is high in the Basin.

Flow

The monitoring station at Golden Valley and Hazen reported mean flows for the period-of-record (1963-73) of 340 cfs and 392 cfs, respectively (Figure I-B.6-1). The upstream monitoring station at Manning reported only two stream flow measurements which averaged 8 cfs. Flows in the Knife River varied from almost no flow to 9620 cfs at the Golden Valley monitoring station. Zero flows are not uncommon, but flowing springs maintain pools in many areas. Maximum flows, however, rarely exceeded 2000 cfs at any location and flooding is rarely recorded.

Trace Metals

Very little data are available for trace metals concentrations in the Knife River. Only one analysis has been reported for copper and zinc concentrations, that collected in 1965 near Golden Valley. The reported concentrations were 40 and 20 ug/l, respectively. Fluoride and boron concentration were measured at all three locations. The mean concentrations at the two (downstream) stations

Table 1-8.6-1. Water quality data summary from selected stations on the Knife River.

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Dissolved Hg µg/l	F µg/l	Se µg/l	Metals Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Knife River at Manning, N. Dakota 06339100																			
No. of samples	2	-	-	2	2	2	-	1 [6]	-	-	-	-	-	2	-	-	2	-	8
Maximum value	7.5	-	-	8.1	11	990	-	0.22	-	-	-	-	-	200	-	-	170.0	-	240
Minimum value	5.0	-	-	7.8	6	800	-	0.22	-	-	-	-	-	200	-	-	70.0	-	210
Mean value	6.2	-	-	8.0	8	895	-	0.22	-	-	-	-	-	200	-	-	120.0	-	225
Period of Record	72-73	-	-	72-73	72-73	72-73	-	1973	-	-	-	-	-	72-73	-	-	72-73	-	72-73
Location and STORET No. Knife River near Golden Valley, N. Dak. 06339500																			
No. of samples	51	-	-	107	140	105	30	105 [8]	43 [10]	2	-	1	-	107	-	-	107	1	107
Maximum value	23.9	-	-	8.6	9620	2700	3340	2.10	7.66	0.58	-	40.0	-	900	-	-	1200.0	20.0	450
Minimum value	0.0	-	-	6.6	.2	114	65	0.04	0.58	0.05	-	40.0	-	100	-	-	50.0	20.0	46
Mean value	9.6	-	-	7.8	340	1004	1201	0.52	3.17	0.32	-	40.0	-	456	-	-	257.5	20.0	211
Period of Record	63-73	-	-	63-73	63-73	63-73	63-65	63-73	64-65	65-72	-	1965	-	63-73	-	-	63-73	1965	63-73
Location and STORET No. Knife River at Hazen, N. Dak. 06340500																			
No. of samples	24	-	-	28	28	28	-	9 [6]	-	-	-	-	-	28	-	-	28	-	28
Maximum value	24.0	-	-	8.3	5930	1510	-	0.54	-	-	-	-	-	900	-	-	1300.0	-	530
Minimum value	0.0	-	-	7.0	13	204	-	0.00	-	-	-	-	-	0	-	-	0.0	-	81
Mean value	9.1	-	-	7.9	392	1004	-	0.26	-	-	-	-	-	400	-	-	263.2	-	320
Period of Record	69-73	-	-	69-73	69-73	69-73	-	70-73	-	-	-	-	-	69-73	-	-	69-73	-	69-73

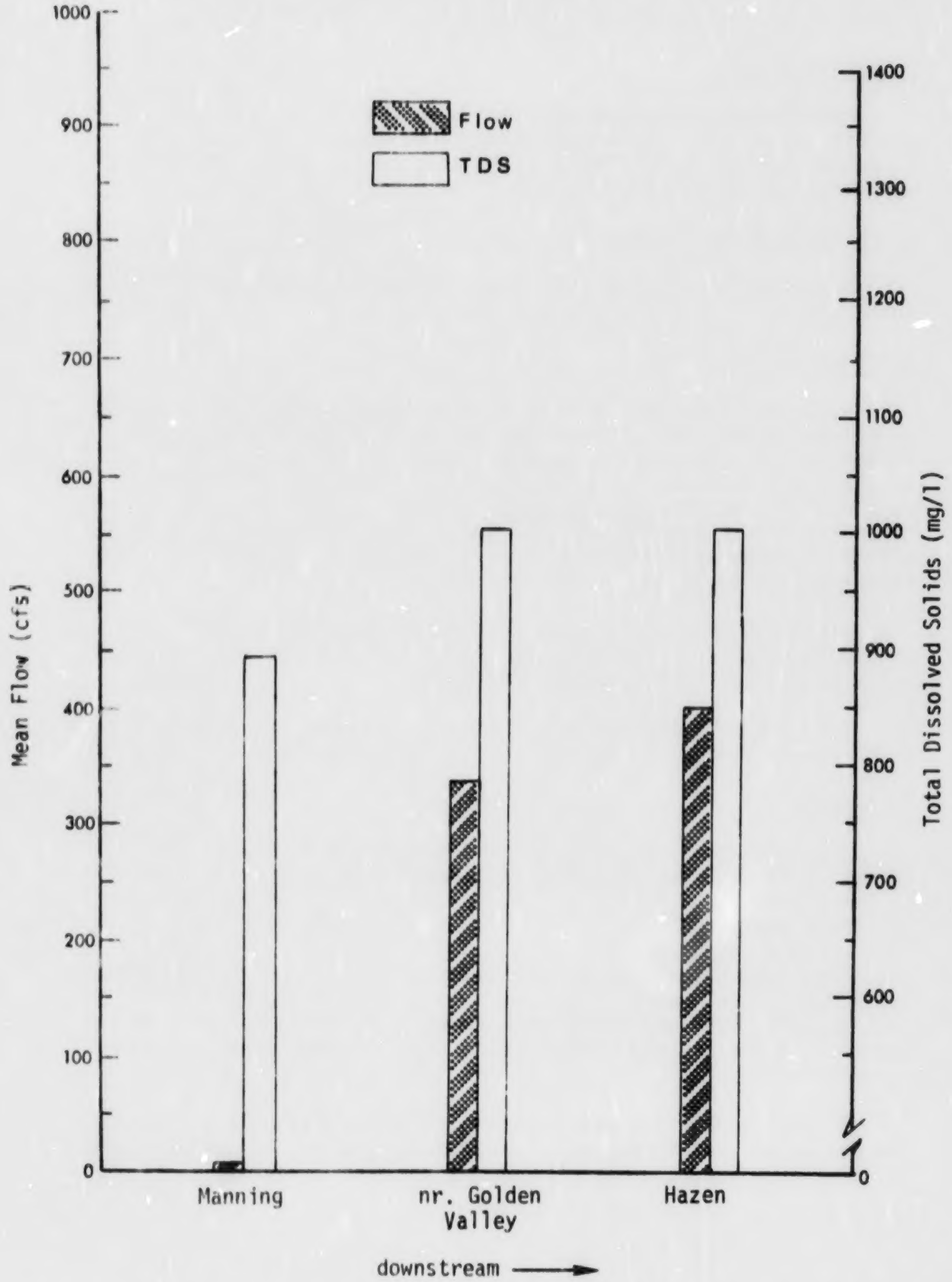

Fig. I-B.6-1 Mean flow and mean total dissolved solids for the period-of-record for selected sampling points on the Knife River.

reporting a significant number of analyses were 430 ug/l for fluoride and 260 ug/l for boron. Waters tested from springs in 1972 showed ferrous iron concentrations exceeding 3 mg/l seasonally.

Suspended Solids

Measurements for suspended solids in the Knife River are represented only by the 30 values obtained between 1963 and 1965 at Golden Valley, North Dakota. The mean concentration was 1201 mg/l with values ranging from 114 to 3340 mg/l.

Biochemical Oxygen Demand

No values for biochemical oxygen demand were reported for the Knife River.

Nutrients

More than ten times as many nitrate measurements were recorded at Golden Valley than at the other two monitoring stations. The Golden Valley measurements, however, were all initially reported as dissolved nitrate, not as N. No attempt has been made to correlate dissolved nitrate with total nitrate. The mean total nitrate concentration at Manning was 0.22 mg/l (as N). The mean dissolved nitrate concentration was 0.52 mg/l (as N) at Golden Valley and the mean total was 0.26 mg/l (as N) at Hazen.

Dissolved ammonia nitrogen concentrations were reported from only Golden Valley - resulting in a mean concentration of 3.17 mg/l and a maximum concentration of 7.66 mg/l.

The Golden Valley monitoring station reported the only phosphate measurements (two), the mean being 0.32 mg/l (as P).

Temperature

A maximum temperature of 24° C was recorded at Hazen, North Dakota in 1964. Mean temperatures generally were reported near 10° C.

d. The Fishery

Fish population studies have been carried out in the Knife River Basin for several years. Data are available from the main river surveys in 1957, 1964 and 1972. Only three impoundments within the basin support a sport fishery. Fish populations in these areas are monitored annually.

A total of 35 fish species were collected from waters within the basin the past three years. A list of species indicating their relative abundance and distribution is included as Table I-B.6-2.

Table I-B.6-2

Knife River Basin Fishery

Geographic Areas

1. North Fork:	Headwaters to confluence with the south fork at Beulah (Spring Creek).
2. South Fork:	Headwaters to confluence with north fork at Beulah.
3. Lower Area:	Knife River main channel and tributaries from Beulah to the Missouri River.

Relative Abundance in Each Geographic Area*

Species	1. North Fork	2. South Fork	3. Lower Area
Rainbow trout	absent	common	rare
Goldeye	absent	rare	common
Northern pike	common	rare	rare
Northern redbelly dace	rare	common	absent
Carp	abundant	common	common
Brassy minnow	rare	rare	absent
Northern plains minnow	common	common	rare
Flathead chub	rare	common	rare
Lake chub	rare	rare	absent
Common shiner	common	common	common
Emerald shiner	abundant	abundant	abundant
Plains shiner	rare	common	absent
Bluntnose minnow	absent	common	rare
Fathead minnow	common	common	rare
Blacknose dace	absent	rare	rare
Creek chub	rare	abundant	abundant
River carpsucker	absent	absent	rare
White sucker	common	common	rare
Northern redhorse	common	common	rare
Black bullhead	abundant	common	common
Channel catfish	absent	rare	common
Stonecat	common	common	rare
Brook stickleback	rare	rare	rare
White bass	absent	absent	rare
Green sunfish	rare	rare	absent
Pumpkinseed	rare	rare	absent
Orange spotted sunfish	rare	rare	rare
Bluegill	rare	rare	absent
Largemouth bass	rare	rare	absent
White crappie	rare	rare	absent
Iowa darter	rare	rare	absent
Yellow perch	common	rare	absent
Sauger	absent	absent	common

Table I-B.6-2 continued

Species	1. North Fork	2. South Fork	3. Lower Area
Walleye	rare	rare	common
Freshwater drum	absent	absent	common

* Relative Abundance

Absent:	No specimens taken within the designated geographic areas.
Rare:	One specimen taken at one or more sampling stations.
Common:	One to ten specimens taken at one or more sampling stations.
Abundant:	More than ten specimens taken at more than one sampling station.

Creel census data from 1969, 1970 and 1973 indicate the lower Knife River furnishes a good sport fishery. Species taken in order of abundance are channel catfish, walleye, sauger, northern pike and white bass. Bullhead, northern pike, yellow perch and rainbow trout provide the major fishery in managed impoundments.

The sport fishery impact on the Knife River is relatively high with catch per angler-hour of 1.02 or well above the statewide average of .37. The three-year average of 1.02 fish per angler hour was computed from the Knife River. Values ranged from a low of .34 in 1970 to a high of 3.3 in 1973.

Heavy flows high in silts prevent upstream migration of several species. Species residing in the river and its tributaries, particularly the cyprinids, rely upon seasonal flows for distribution and establishment of habitat.

Reproduction from twelve species of minnows and the white sucker were documented in a 1972 survey. Reproduction of game fish species, when it occurs, is not important to the total fishery. The reproduction of minnows is important to migrating prey species and supplements the Missouri River and Oahe Reservoir fishery.

The addition of structures to impound water or of industrial discharges that would change the water quality would be detrimental to the aquatic populations in the Knife River. Reduced or stabilized flows would depress total production of the river. The diversity of habitat now existing as a result of seasonal flows would be lost. Species composition and abundance would change to fit the new environment. Many native stream fish now found in abundance would be much reduced in number or cease to exist. The sport fishery is also dependent upon seasonal migration. A change in the quantity and quality of the sport fish creel would most likely result from mechanically changing the habitat now existing in the Knife River Basin.

I-B.7 Heart River Basin

a. The Basin

The Heart River rises on the Little Missouri Divide and drains approximately 3,900 square miles in southwestern-central North Dakota. The river and its tributaries meander an estimated 510 miles with an average gradient of 3.8 feet per mile. The drainage area includes rugged plateau lands, terraced lands and rolling to gently sloping prairies.

The annual precipitation averages about 15 inches. Most moisture comes in the form of rain in May and June. Snow accumulations rarely exceed 16 inches. Heavy rains and snows are recorded and cause periodic flooding.

Soils vary from the steep badlands type to dark, brown clays. Alkaline soils occur in many areas particularly in the upper basin and along the Green River, a headwaters tributary. In many areas the upper soils are sandy and highly susceptible to wind and water erosion. Hardwood stands with a brushy understory were continuous along the river channels prior to encroachment by man. Accumulated livestock waste add to the nutrient load of the Heart River.

b. Activities Influencing Water Quality

The history of land use in the Heart River Basin follows the pattern of the entire southwestern part of North Dakota. Large cattle and sheep ranches were the settlers' first activity. The large ranches were soon replaced by smaller farms and ranches. At present large diversified operations are in most cases over-utilizing the resource. Row-crop farming is evident on all tillable lands. Because of the lack of adequate annual moisture and poor soil quality, most lands are cropped every other year. Such practices leave one-half of the soil tilled exposed increasing the potential for wind and water erosion. Grazing is carried out on all lands not under cultivation. The badlands-type and steeper tributary and main channel areas are severely grazed. Most operators also winter vast numbers of cattle in the "bottoms" which provide protection and water. The protective cover along tributaries and the main channel is continually reduced by over-use.

The Bureau of Reclamation developed the Heart River Project in 1946. The project was proposed for irrigation. Two large impoundments were proposed and constructed. The larger (5,160 acre Heart Butte Reservoir) is located about mid-way in the Heart River Basin. The upper dam (860 acre Dickinson Reservoir) is now used as a source of municipal water in addition to irrigation. Land use changes below these impoundments are not significant but the river hydrology and water quality were greatly affected.

Lignite coal deposits are known to exist throughout most of the Heart River Basin. Development to date is restricted to small operations supplying coal for local consumption. Speculators have been rapidly obtaining mineral leases in anticipation of the vast gasification and generating plants proposed.

c. Water Quality

The two large impoundments and several smaller impoundments on tributary streams changed the Heart River from a free-flowing stream to a lake-stream complex. The two main-stem impoundments serve as silt basins improving the water quality progressively downstream. An increase in nutrients in the reservoirs, however, has adversely affected the water quality behind the reservoirs and changed aquatic populations. Fish distribution throughout the basin by migration is no longer possible from a single source, namely the Missouri River.

Silts high in nutrients have been detrimental to the water quality of the basin. High nitrogen and phosphorus levels are seasonally present. Phenols from oil fields and a refinery operation reduce fish flesh quality and increase municipal water supply treatment processing. The headwaters above Dickinson Reservoir drain the "Little Badlands" which contain exposed bentonite deposits. Heavy rains and spring runoff carry bentonite down the Heart River to the impoundments where it remains in suspension until water temperatures drop below 5° centigrade. The severity of turbidity caused by bentonite suspension depends upon flow volume. Dickinson Reservoir is severely affected annually and the effects are reflected in the existing aquatic populations in the reservoir and Heart River above. Heart Butte Reservoir is severely affected by bentonite suspension only in years of very high flow.

The Green River, a tributary to the Heart River, is unique in southwestern North Dakota. Water quality combined with desirable habitat classifies this was a fresh-water stream. Rock, rubble and sand provide the stream base in many areas. Springs are numerous providing a continuous supply of good quality water. Spring·flows, combined with intermittent beaver dams, provide habitat where fish survival is assured even in the driest periods. The existing aquatic population reflects these attributes. The water is relatively hard with a pH reportedly around 8.2. Total specific conductivity varies seasonally but often exceeds 2,100 micromhos. The Green River has long been a main source of bait minnows for the sport fishermen in the area.

Water quality in the lower Heart River is dependent upon flows, but it is usually good and conductive to the production and survival of a diversified aquatic population. These populations are dependent upon seasonal upstream and downstream migrations. In periods of low seasonal flows migration is obstructed by chemical effluent from the oil refinery at Mandan and impounding structures. Heavy silt loads in high flow periods are also a deterrent to upstream movement of desirable sport fishes.

A summary of water quality in the Heart River, based on data reported from three USGS monitoring stations and two North Dakota State monitoring stations operating at four separate locations (Table I-B.7-1) has been prepared. The USGS station on the headwaters at New Hradec and the mainstem at Richardton have been in operation only since 1972 and have reported two and four measurements, respectively. A brief history of several selected water quality parameters for the period-of-record at each sampling station is presented in the following sections.

pH

Average pH values ranged from 7.8 at three locations to 8.0 at Mandan. The range of single pH values was from 6.8 to 9.1.

Dissolved Oxygen

Dissolved oxygen data were reported for only two stations, the North Dakota State stations at Dickinson and Mandan. Both stations reported minimum dissolved oxygen values less than 4 mg/l. The Dickinson station reported several dissolved oxygen concentrations of 0 mg/l, the low values usually occurring during the winter months. When all low dissolved oxygen values are included in the period-of-record computed mean concentration, the two stations still have mean dissolved oxygen concentrations of 8.5 and 9.6 mg/l, respectively.

Total Dissolved Solids

Total dissolved solids concentrations were measured at all 5 sampling sites. The period-of-record average concentrations (in downstream order) were 712, 904, 1123, 699, and 844 mg/l, respectively. The 1123 mg/l concentration at Richardton is the average of only four measurements. The maximum TDS concentration reported was 2280 mg/l, while the minimum reported concentration was 156 mg/l, both values being reported from the Mandan sampling station.

Flow

Only 17 flow measurements have been recorded in the STORET system since 1971 (New Hradec, Richardton, and Mandan sampling sites). Consequently, mean flow data reported herein should not be viewed as an accurate estimate of stream flow in the Heart River. Mean flows at the three stations were 6, 83, 979 cfs, respectively (Figure I-B.7-1). The maximum flow of 8250 cfs was recorded at Mandan in March, 1972, while minimum flows less than 10 cfs were recorded at both the New Hradec and Mandan stations.

Table I-8.7-1. Water quality data summary from selected stations on the Heart River.

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Dissolved Metals Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Heart River Headwaters Green River near New Hradec 06344600																			
No. of samples	1	-	-	2	2	2	-	2 8/	-	2 11/	-	-	-	2	-	-	2	-	2
Maximum value	12.0	-	-	8.1	7.0	837	-	0.45	-	0.06	-	-	-	300	-	-	460.0	-	290
Minimum value	12.0	-	-	7.6	5.6	588	-	0.22	-	0.00	-	-	-	100	-	-	90.0	-	160
Mean value	12.0	-	-	7.8	6.3	712	-	0.34	-	0.03	-	-	-	200	-	-	275.0	-	225
Period of Record	1973	-	-	72-73	72-73	72-73	-	72-73	-	72-73	-	-	-	72-73	-	-	72-73	-	72-73
Location and STORET No. Heart River Dickinson, N.D. 380023																			
No. of samples	63	63	62	63	-	62 2/	-	-	-	27 5/	-	-	-	-	-	-	-	-	63
Maximum value	24.0	15.4	138.0	9.1	-	1600	-	-	-	0.78	-	-	-	-	-	-	-	-	450
Minimum value	0.0	0.0	1.5	6.8	-	190	-	-	-	0/03	-	-	-	-	-	-	-	-	45
Mean value	9.3	8.5	9.1	7.9	-	904	-	-	-	0.13	-	-	-	-	-	-	-	-	240
Period of Record	68-73	68-73	68-73	68-73	-	68-73	-	-	-	71-73	-	-	-	-	-	-	-	-	68-73
Location and STORET No. Heart River near Richardton, N. Dak. 06345500																			
No. of samples	4	-	-	4	3	4	-	4 8/	-	4 11/	-	-	-	4	-	-	4	-	4
Maximum value	22.5	-	-	8.1	151	1510	-	0.45	-	0.16	-	-	-	300	-	-	410.0	-	650
Minimum value	8.5	-	-	7.4	34	777	-	0.22	-	0.00	-	-	-	100	-	-	90.0	-	271
Mean value	15.2	-	-	7.8	83	1123	-	0.28	-	0.08	-	-	-	225	-	-	202.0	-	450
Period of Record	72-73	-	-	72-73	72-73	72-73	-	72-73	-	72-73	-	-	-	72-73	-	-	72-73	-	72-73

Table I-8.7-1 (contin.).

													Dissolved				Metals			
	Temp C	DO mg/1	BOD mg/1	pH units	flow cfs	TDS mg/1	SS mg/1	T-NO_3 as N mg/1	NH_3 mg/1	T-PO_4 as P mg/1	Pb µg/1	Cu µg/1	Hg µg/1	F µg/1	Se µg/1	Al µg/1	B µg/1	Zn µg/1	Total hardness mg/1
Location and STORET No. Heart River near Mandan, N. D. 06349000																			
No. of samples	11	-	-	12	12	12	-	12 8/	-	12 11/	-	-	-	12	-	-	12	-	12
Maximum value	26.5	-	-	8.2	8250	1110	-	1.6	-	0.14	-	-	-	800	-	-	580.0	-	420
Minimum value	0.0	-	-	7.0	10	156	-	0.22	-	0.0	-	-	-	100	-	-	0.0	-	67
Mean value	11.4	-	-	7.8	979	699	-	0.55	-	0.02	-	-	-	325	-	-	204.0	-	268
Period of Record	71-72	-	-	71-72	71-72	71-72	-	71-72	-	71-72	-	-	-	71-72	-	-	71-72	-	71-72
Location and STORET No. Heart River Mandan, N. Dak. 380024																			
No. of samples	63	63	63	63	-	60	-	-	-	26 5/	-	-	-	-	-	-	-	-	63
Maximum value	25.0	16.2	8.9	9.0	-	2280	-	-	-	0.25	-	-	-	-	-	-	-	-	515
Minimum value	0.0	3.7	0.8	7.0	-	175	-	-	-	0.00	-	-	-	-	-	-	-	-	110
Mean value	10.3	9.6	2.9	8.0	-	844	-	-	-	0.04	-	-	-	-	-	-	-	-	290
Period of Record	68-73	68-73	68-73	68-73	-	68-73	-	-	-	71-73	-	-	-	-	-	-	-	-	68-73

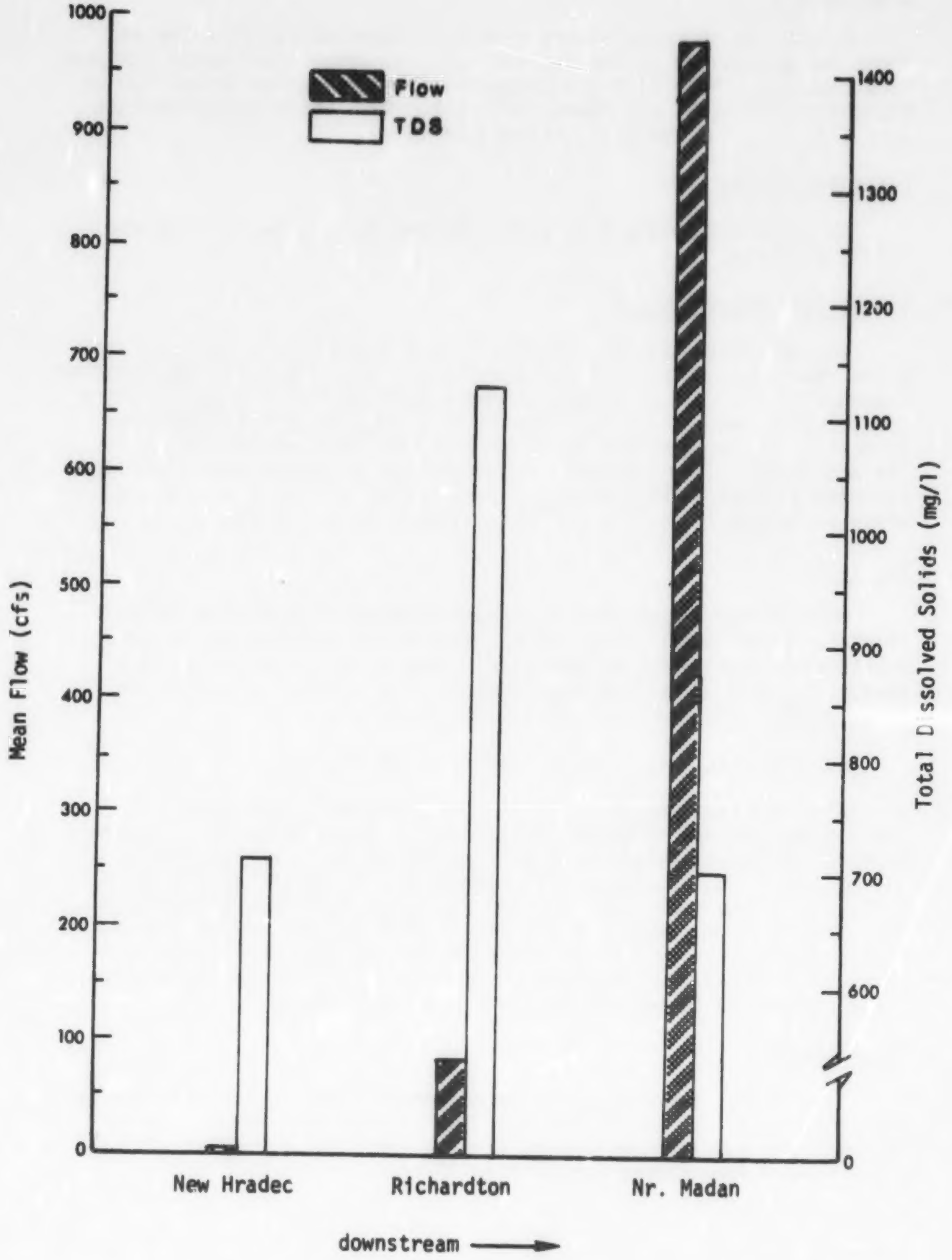

Fig. I-B.7-1 Mean flow and mean total dissolved solids for the period-of record for selected sampling points on the Heart River.

Trace Metals

A total of 18 measurements each were reported for fluoride and boron concentrations in the Heart River. No other trace metal analyses were reported. Mean fluoride concentrations were: New Hradec-200 ug/l, Richardton-225 ug/l, and Mandan 325 ug/l. Mean boron concentrations were 275, 202, and 284 ug/l, respectively.

Suspended Solids

No suspended solids data were reported for the Heart River monitoring stations.

Biochemical Oxygen Demand

The two State stations (Dickinson and Mandan) were the only stations reporting BOD results for the Heart River. The Dickinson station reported two BOD values greater than 16 mg/l (one of 138 gm/l) with a conservative mean of 6.3 mg/l (omitting the two values greater than 16 mg/l). In February and March of 1970 when BOD concentrations of 138 and 52 mg/l were reported, the dissolved oxygen concentration was reported as zero. The mean BOD concentration at Dickinson was 9.3, while at Mandan it was 2.9 mg/l with a maximum of 8.9 mg/l.

Nutrients

Nitrate (NO_3) concentrations were reported as dissolved nitrate from the three USGS stations at New Hradec, Richardton, and Mandan. Mean dissolved nitrate concentrations ranged from 0.28 mg/l as N at Richardton to 0.55 mg/l as N at Mandan. The maximum concentration reported was 1.60 mg/l as N at the Mandan station.

No data were reported for ammonia concentrations.

All five stations reported phosphate concentration data. The three USGS stations reported average ortho-phosphate ($O\text{-}PO_4$) concentrations of approximately 0.04 mg/l as PO_4 at all three locations. The maximum $O\text{-}PO_4$ concentration reported was 0.16 mg/l as PO_4 at Richardton. The two state-operated stations (Dickinson and Mandan) reported total phosphate concentrations of 0.13 and 0.04 mg/l as P, respectively. Except for one concentration of 0.78 mg/l $T\text{-}PO_4$ as P reported at Dickinson, the maximum concentration reported from either State station in 52 measurements was 0.27 mg/l PO_4 as P.

Temperature

The maximum temperature reported from all monitoring stations on the Heart River was 26.5° C at the USGS station near Mandan, North Dakota. The average temperature for the period-of-record at all stations ranged from approximately 9 to 15° C.

d. The Fishery

The 45 different species of fish found within the Heart River Basin are located geographically according to acceptable habitat relative abundance and species distribution (see attached list). Species composition and abundance is inter-related and in many cases, one is directly dependent upon the reproductive success of the other. The major sport fish population in the nine major impoundments within the watershed are maintained by hatchery stock. The river fishery above each impoundment is dependent upon migration of these stocks. The exception to this is the area below Heart Butte Dam where most game species migrate upstream. Downstream movement over Heart Butte Dam of white bass, walleye and yellow perch has been documented. The source of the catfish population in the Heart River Basin is under investigation. Reproduction of these species is known to occur in and or above Heart Butte Reservoir. It is also possible reproduction occurs in the main channel below Heart Butte Dam.

The lower Heart River Basin is the most important sport fish area in southwestern North Dakota. Creel census data from 1969, 1970 and 1973 revealed impact on the Heart River and impoundments within the basin receive more man-days use than all other areas combined (Garrison Reservoir and Oahe Reservoir not included in these estimates).

Fishing success in the two large impoundments (Heart Butte Reservoir and Dickinson Reservoir) is below the statewide average of .37 fish per angler hour. Success on smaller impoundments including two trout ponds is above the statewide average. Man-days use on the lower Heart River is very high and exceeds the total man-days use on the two large impoundments. Fishing success for this area is well above the statewide average. Estimates were obtained from reported game fish catches. Species reported in the creel include walleye, sauger, white bass, northern pike, channel catfish, yellow perch and crappie. Catch per angler hour varied from a low of .75 to a high of 1.1 in three reporting years.

Intensive management practices have improved the fishery throughout the Heart River Basin where water quality and reservoir design will support a fishery. Sub-impoundment rearing areas to supplement walleye populations, species composition manipulation, and lake and stream renovation are but a few of the management practices employed to improve the fishery. The river fishery, however, is still dependent upon seasonal flows for up- and downstream migration and the establishment of habitat.

Further deterioration of water quality, reduced regulated flows, and increased silt loads would shorten reservoir life and eliminate or degrade aquatic populations in the remaining free-flowing areas of the Heart River. Table I-B.7-2 shows relative abundance of fish in the Heart River.

Table I-B.7-2

Heart River Basin Fishery

Geographic Areas

1. Headwaters	The Green River, Antelope Creek and that portion of the Heart River Mainstem above and including Dickinson Reservoir.
2. Central Area:	The Heart River Mainstem and tributaries from Dickinson Dam to and including Heart Butte Reservoir.
3. Lower Area:	The Heart River Mainstem and tributaries from Heart Butte Reservoir to the Missouri River.

Relative Abundance in Each Geographic Area*

Species	1. Headwaters	2. Central Area	3. Lower Area
Gar	absent	absent	rare
Rainbow trout	absent	rare	rare
Goldeye	absent	rare	common
Northern pike	common	common	common
Northern redbelly dace	abundant	rare	rare
Carp	common	common	rare
Brassy minnow	rare	rare	absent
Silvery minnow	rare	rare	rare
Northern plains minnow	rare	common	rare
Sturgeon chub	rare	rare	rare
Flathead chub	common	common	common
Lake chub	rare	common	rare
Golden shiner	absent	common	rare
Emerald shiner	rare	rare	absent
Spottail shiner	rare	absent	absent
Common shiner	common	rare	rare
Plains shiner	rare	absent	absent
Bluntnose minnow	rare	rare	absent
Fathead minnow	abundant	common	common
Blacknose dace	rare	rare	absent
Longnose dace	common	rare	absent
Creek chub	common	rare	absent
River carpsucker	rare	abundant	common
White sucker	abundant	common	rare
Bigmouth buffalo	absent	rare	rare
Northern redhorse	common	common	common
Black bullhead	common	common	common
Channel catfish	common	abundant	abundant
Stonecat	common	common	common
Tadpole madtom	absent	rare	rare

Table I-B.7-2 continued

Species	1. Headwaters	2. Central Area	3. Lower Area
Brook stickleback	rare	rare	absent
White bass	absent	abundant	abundant
Green sunfish	rare	rare	rare
Orange spotted sunfish	absent	rare	rare
Bluegill	common	common	rare
Smallmouth bass	absent	rare	absent
Largemouth bass	common	common	rare
White crappie	abundant	abundant	common
Black crappie	common	common	rare
Iowa darter	abundant	common	rare
Johnny darter	rare	rare	absent
Yellow perch	common	common	rare
Sauger	absent	rare	common
Walleye	common	abundant	common
Freshwater drum	absent	absent	rare

* Relative Abundance

Absent:	No specimens taken within the designated geographic areas.
Rare:	One specimen taken at one or more sampling stations.
Common:	One to ten specimens taken at one or more sampling stations.
Abundant:	More than ten specimens taken at more than one sampling station.

I-8.8 Cannonball River Basin

a. The Basin

The Cannonball River rises on the Little Missouri Divide and drains approximately 4,400 square miles in southwestern North Dakota. Ninety-six square miles of the total is located in extreme northern South Dakota. The river and its tributaries meander some 550 miles through rugged plateau lands, level bench lands, and rolling prairies.

Soils throughout the drainage vary as greatly as the terrain. The dark brown, hilly and steep land and alkaline soils of the semi-arid grasslands are typical of the area. Soils within the entire basin are highly susceptible to wind and water erosion when not properly protected.

The annual precipitation averages about 15 inches but varies greatly from year to year. Rainfall from April through September accounts for 70 percent with the remaining 30 percent coming in the form of snow. Often much of the annual precipitation comes as heavy rains causing flooding conditions and severe erosion. These conditions are also caused periodically by a rapid thawing of accumulated snows. Extremes in flows recorded by the USGS at Breien, North Dakota, have been 0 to 94,800 cfs. Periods of no flow are not uncommon, especially during the dry months of August and September.

b. Activities Influencing Water Quality

The Cannonball River Basin lies within the Great Plains region. When first settled, large ranches were operated throughout the basin. At this time it was typified by rolling grasslands and woody draws. The large holdings were then replaced by small farms and ranches. With the advent of industrialized agriculture, however, large holdings are again common. Intensive row-crop cultivation and livestock grazing is now evident on nearly all lands within the basin. Erosion throughout the Cannonball River Basin has adversely affected the tributary and mainstem profile.

c. Water Quality

Water samples analyzed from throughout the basin vary in their chemical composition. A pH range of 7.2 to 8.4 from the river channel to an impoundment is not uncommon, nor is it unrealistic to find variations in conductivity of 440 to 1,900 micromhos over the same stretch.

Productivity is high in all impoundments and the tributaries and mainstem channel. The continued increase in nutrient levels and loss of storage by siltation continually degrades water quality and makes sport fish management difficult. Life expectancy of any impoundment in the Cannonball River Basin will be short unless a change in land use is implemented before closure. Any one of the existing impoundments within the basin could be used as a dramatic example of eutrophication.

A summary of current water quality information for the Cannonball River based on reported data (1964-73) from three USGS monitoring stations and one North Dakota State station (Table I-8.8-1) has been completed. The USGS monitoring station at Breien, North Dakota has been inactive since 1972, while the USGS station near Bentley has been active since only 1972. A brief summary of several selected water quality parameters for the period-of-record at each sampling site is presented in the following sections.

pH

The reported pH range in the Cannonball River is normal, with a mean of about 7.9, maximum value of 8.9 and a minimum value of 6.8. The highest value was recorded at the State monitoring station at Regent, North Dakota. Mean values for pH in downstream order were: 7.9, 8.1, and 7.8.

Dissolved Oxygen

The State station at Regent was the only station reporting dissolved oxygen concentrations in the Cannonball River. A total of 24 measurements since 1968 showed a mean dissolved oxygen concentration of 10.1 mg/l and a range of 6.7 to 15.7 mg/l.

Total Dissolved Solids

Average TDS concentrations in the Cannonball River varied from 836 mg/l at Regent (USGS station) to 1598 mg/l near Bentley (Figure I-8.8.1). The maximum concentration measured was 2690 mg/l near Bentley, while the minimum concentration of 30 mg/l was measured at the USGS station at Regent.

Flow

Historical flow data were reported from only the three USGS-operated stations at Regent, Bentley, and Breien. The mean period-of-record flows recorded at each station were 270, 285, and 414 cfs, respectively. Stream flow in the Cannonball River appeared to be seasonal as evidenced by highest reported flows during spring runoff periods.

Trace Metals

The only metals data reported for the Cannonball River were for fluoride and boron. A combined total of approximately 100 measurements were made for each parameter at the three USGS monitoring stations. Mean fluoride concentrations in downstream order were: 423 ug/l at Regent, 238 ug/l at Bentley, and 540 ug/l at Breien. Mean boron concentrations for the same three locations were 382, 414, and 308 ug/l, respectively.

Table [illegible] [illegible] from selected stations on the [illegible] River.

	Temp °C	DO mg/l	BOD mg/l	pH units	Flow cfs	[illegible] mg/l	[illegible] mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	[illegible] mg/l	[illegible] mg/l	Dissolved [illegible] mg/l	Dissolved [illegible] mg/l	[illegible] mg/l	Metals [illegible] µg/l	Metals [illegible] µg/l	[illegible] µg/l	Total hardness mg/l
Location and STORET No. [illegible]																			
No. of samples	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	65	-	66
Maximum value	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	780.0	-	730
Minimum value	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	8.0	-	48
Mean value	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	302.0	-	303
Period of record	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	66-73	-	66-73
Location and STORET No. [illegible]																			
No. of samples	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	-	-	-	-	-	-	26
Maximum value	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	-	-	-	-	-	-	770
Minimum value	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	-	-	-	-	-	-	120
Mean value	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	-	-	-	-	-	-	376
Period of record	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	-	-	-	-	-	-	68-73
Location and STORET No. [illegible]																			
No. of samples	8	-	-	[illegible]	[illegible]	8	-	[illegible]	-	[illegible]	-	-	-	8	-	-	8	-	8
Maximum value	[illegible]	-	-	[illegible]	[illegible]	[illegible]	-	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	940.0	-	1080
Minimum value	[illegible]	-	-	[illegible]	[illegible]	[illegible]	-	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	3.0	-	180
Mean value	[illegible]	-	-	[illegible]	[illegible]	[illegible]	-	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	414.0	-	665
Period of record	[illegible]	-	-	[illegible]	[illegible]	[illegible]	-	[illegible]	-	[illegible]	-	-	-	[illegible]	-	-	73-73	-	73-73

TABLE [illegible] (CONTINUED)

	Temp °C	DO mg/l	BOD mg/l	pH units	Flow cfs	TDS mg/l	[illegible] mg/l	T-NO$_3$ as N mg/l	NO$_2$ mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Dissolved Hg µg/l	Fe µg/l	Cd µg/l	Metals Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. [illegible] at [illegible], N. Y. [illegible]																			
No. of samples	35	-	-	20	36	19	-	5	-	11	-	-	-	26	-	-	21	-	26
Maximum value	26.0	-	-	8.3	[illegible]	[illegible]	-	1.98	-	0.37	-	-	-	1400	-	-	860.0	-	720
Minimum value	3.0	-	-	7.2	16	192	-	0.22	-	0.1	-	-	-	100	-	-	0.0	-	140
Mean value	15.2	-	-	7.7	604	[illegible]	-	1.02	-	0.17	-	-	-	346	-	-	346.0	-	429
Period of Record	70-72	-	-	70-72	70-72	70-72	-	70-72	-	70-72	-	-	-	70-72	-	-	70-72	-	70-72

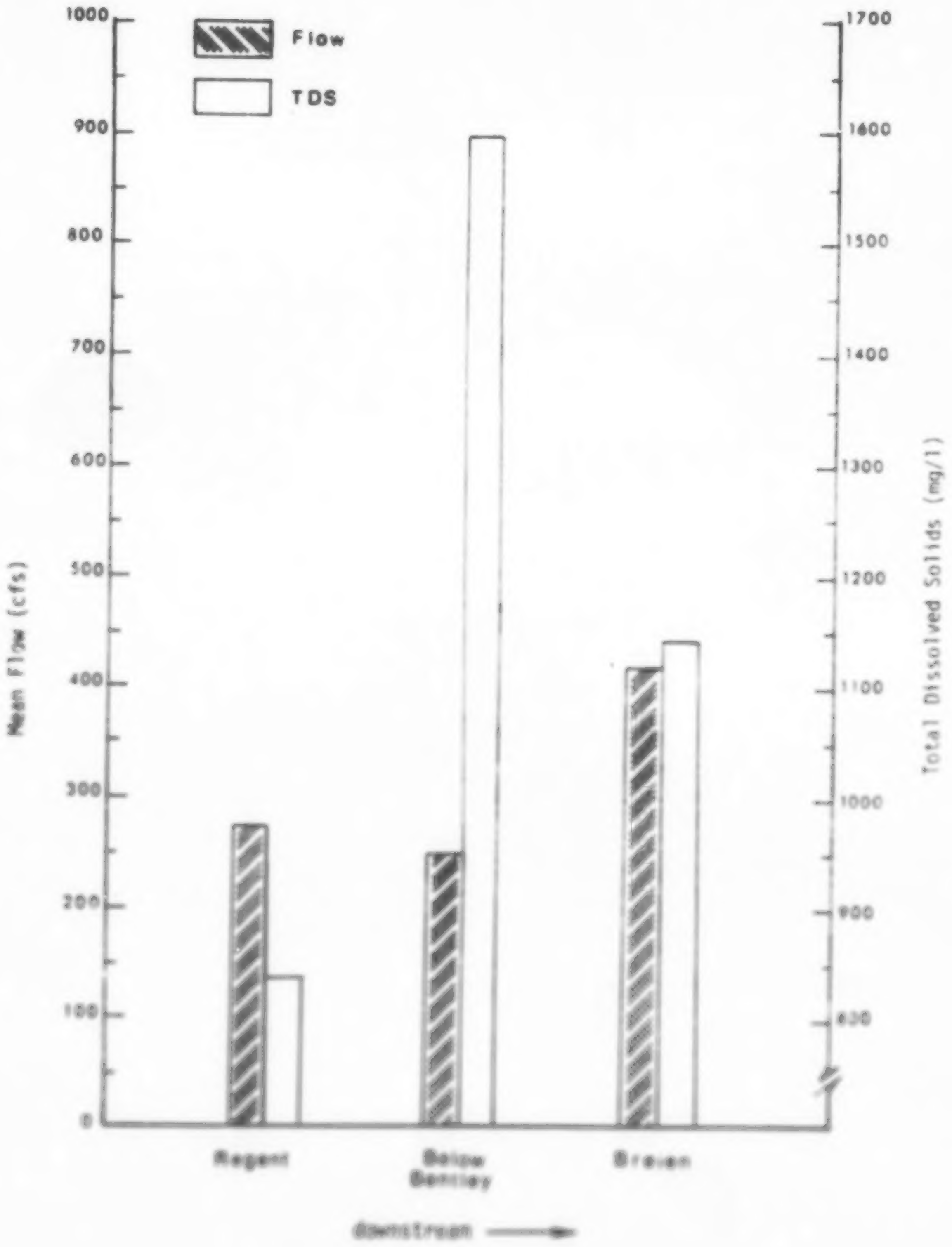

Fig. I-B.8-1 Mean flow and mean total dissolved solids for the period-of-record for selected sampling points on the Cannonball River.

Suspended Solids

The only suspended solids data reported were 18 measurements from the Regent monitoring location for the period 1964-1966. The mean suspended solids concentration was 1110 mg/l while the maximum concentration was 6080 mg/l. This maximum concentration occurred in May, 1965 during high spring runoff.

Biochemical Oxygen Demand

The State monitoring station at Regent provided the only BOD data for the Cannonball River. A total of 23 measurements since 1968 resulted in an average BOD concentration of 3.7 mg/l and a maximum concentration of 13.0 mg/l.

Nutrients

A small amount of nutrient data (78 measurements) were recorded in the STORET data system from the four monitoring stations on the Cannonball River for the period-of-record (1965-73). Data consisted of total nitrate concentrations and total and dissolved phosphate concentrations. The average nitrate concentrations (as N) for the period-of-record were: 0.45 mg/l at Regent, 0.97 mg/l at Bentley, and 0.60 mg/l at Breien (upstream to downstream order). A relatively high maximum concentration of 2.94 mg/l NO_3 (as N) was recorded in January, 1973 at the Bentley monitoring site. Another high value of 2.61 mg/l dissolved nitrate (as N) was measured earlier in April, 1972, also at Bentley. Aside from the two high values recorded at Bentley, all other nitrate concentrations at all three stations were less than 1.25 mg/l NO_3 (as N).

A combined total of 24 measurements for ortho-phosphate were made at Bentley and Breien, resulting in mean concentrations of 0.03 and 0.01 mg/l (as P), respectively. The maximum concentration recorded at both locations was 0.07 mg/l. Total phosphate concentrations were measured a combined total of 12 times at the State and USGS monitoring sites at Regent, North Dakota with mean concentrations of 0 and 0.10 mg/l (as P), respectively. Only two measurements were recorded for the State station, however, both measurements being 0 (0.01 mg/l as PO_4). The maximum concentration at the USGS station was 0.75 mg/l (as P).

No ammonia data were reported for the Cannonball River.

Temperature

Mean temperatures in the Cannonball River were generally between 7° and 10° C. The maximum temperature ranged from 22.5° C near Bentley to 28° C at Regent.

d. The Fishery

Fish population surveys conducted throughout the Cannonball River Basin have identified 29 different species. Relative abundance varies greatly from impoundment to tributary, tributary to the main channel, and progressively from headwaters to Oahe Reservoir. A summary of fishes, their geographic distribution within the basin and their relative abundance is attached.

The sport fishery of the entire basin is directly dependent upon hatchery-stocked fish and upstream and downstream movement. Natural reproduction within the main channel is limited primarily to non-game species. Reproduction is important, however, particularly that of the cyprinids which are the main forage species contributing to the mainstem and Oahe Reservoir fishery. In periods of high flow, fish migrate distributing their numbers according to acceptable habitat. Impounding structures, siltation and water quality restrict these movements by species and numbers.

The Cannonball River and its tributaries have 22 major impoundments and hundreds of stock dams and dugouts. Only seven of the larger bodies of water support a sport fishery and four of these are subject to periodic winter kill. Northern pike, rainbow trout, bluegill, bass, and bullhead are the main species harvested from the impoundments. The river fishery is dependent upon peak flows seasonally. Stabilized flows would reduce habitat and restrict migration depressing total productivity.

Records from the 1950's show walleye, sauger, and catfish were the most abundant species taken by anglers. The change in water quality and channel profile is reflected in changes in species composition. Creel census figures from 1969, 1970 and 1973 show in order of abundance, northern pike, bullhead, carp, catfish and a few walleye and white bass now taken by anglers. The sport fishing impact on the Cannonball River is relatively high with catch per unit of effort of 0.54 or above the statewide average of .37 fish per hour. The loss of sport fishing lakes in the area through siltation and eutrophication has forced local anglers to again turn to the main channel of the river for recreation. Table I-8.8-2 shows the relative abundance of fish in the Cannonball River.

Table I-B.8-2

Cannonball River Basin Fishery

Geographic Areas

1.	North Fork:	The Cedar River and tributary from the headwaters to its confluence with the South Fork.
2.	South Fork:	The Cannonball River and its tirbutaries from the headwaters to its confluence with the Cedar River.
3.	Lower Area:	From the confluence of the Cedar and Cannonball River to Oahe Reservoir.

Relative Abundance in Each Geographic Area*

Species	1. North Fork	2. South Fork	3. Lower Area
Rainbow trout	common	common	common
Goldeye	rare	rare	rare
Northern pike	common	common	common
Carp	common	abundant	common
Silvery minnow	rare	common	common
Northern plains minnow	rare	rare	rare
Flathead chub	common	rare	absent
Golden shiner	rare	rare	absent
Flathead minnow	abundant	rare	absent
River carpsucker	rare	abundant	abundant
White sucker	common	rare	abundant
Blue sucker	absent	common	rare
Northern redhorse	rare	absent	rare
Black bullhead	abundant	common	common
Channel catfish	rare	abundant	rare
Stonecat	common	rare	common
Brook stickleback	rare	common	rare
White bass	absent	rare	absent
Green sunfish	rare	absent	rare
Pumpkinseed	rare	common	rare
Orange spotted sunfish	rare	rare	absent
Bluegill	common	rare	rare
Smallmouth bass	common	common	rare
Largemouth bass	rare	absent	absent
White crappie	common	rare	absent
Yellow perch	rare	rare	rare
Sauger	rare	rare	rare
Walleye	common	common	abundant
Freshwater drum	absent	rare	common
		absent	rare

* Relative Abundance

Absent:	No specimens taken within the designated geographic areas.
Rare:	One specimen taken at one or more sampling stations.
Common:	One to ten specimens taken at one or more sampling stations.
Abundant:	More than ten specimens taken at more than one sampling station.

I-B.9 Missouri River (Mainstem through N.D.)

a. The Basin

North Dakota is nearly equally divided by two drainage basins, that of the Missouri River in the West and the Red River of the North to the East. The Missouri River drains that portion of the state south and west of the divide. This area is called the Missouri Plateau and is the largest of the three physiographic areas of the state.

The Missouri Plateau is itself topographically divided by the Missouri River. The area west of the Missouri has a highly developed, dendritic drainage pattern, while the drainage in the area east of the Missouri (Missouri Slope) is weakly developed. The Missouri Plateau has a "cool temperature semi-arid climate." Average annual precipitation for this area is 14 to 16 inches. Warm season precipitation (April to September, inclusive) amounts to 80 percent of the annual precipitation in the west. The extremes in discharge of the Missouri River are results of recharge to a water supply which originates in Montana and Wyoming.

b. Activities Influencing Water Quality

Most of the land along the Missouri River in North Dakota is used in agricultural activities. Grazing and production of cattle forage and cereal wheat grain predominates. Much land along the old river bed has been inundated by reservoirs. The land use within the basin is described in more detail in the previous sections dealing with tributaries of the Missouri River.

c. Water Quality

A summary of current water quality information for the Missouri River in North Dakota, based upon data reported from four active sampling stations and two inactive stations (See Table I-B.9-1) has been completed. A little data exists at both Williston, North Dakota sampling stations; since no samples have been collected since 1970. Of the four active stations, two are located at Bismarck, North Dakota (North Dakota State and EPA-USGS stations). A brief history of several selected water quality parameters for the period-of-record at each sampling location is presented in the following sections.

pH

Measurements for pH have been made at one or more of the six sampling stations since 1957. Only three stations, however, are currently monitoring pH - Culbertson, one at Bismarck, and Pierre. Mean pH values for the period-of-record at the three active stations ranged from 7.6 to 8.0. The North Dakota State station, at Bismarck, Table [illegible]. Water quality data summary from selected stations on the Missouri River.

	Temp C	DO mg/l	BOD mg/l	pH units	Flow cfs	TDS mg/l	SS mg/l	T-NO3 as N mg/l	NH3 mg/l	T-PO4 as P mg/l	Pb ug/l	Cu ug/l	Dissolved Hg ug/l	Dissolved F ug/l	Se ug/l	Metals Al ug/l	Metals B ug/l	Zn ug/l	Total hardness mg/l
Location and STORET No. Mo. R. nr Culbertson, Mont., [illegible]																			
No. of samples	26	26	29	140	176	38	-	26	25	30	3	3	5	68	3	-	60	3	135
Maximum value	22.0	13.2	3.7	8.7	23700	668	-	0.30	0.17	0.52	7.0	22.0	1.0	1200	9.0	-	210.0	19.0	276
Minimum value	0	8.0	0.3	7.2	5333	330	-	0.00	0.00	0.00	0.0	4.0	0.0	400	1.0	-	10.0	0.0	140
Mean value	8.7	10.0	1.5	8.0	12500	411	-	0.05	0.04	0.16	0.7	10.7	0.4	726	4.0	-	102.0	8.7	227
Period of Record	69-73	69-73	69-73	65-73	61-73	67-71	-	69-70	69-72	69-71	70-72	70-72	70-72	65-73	70-72	-	65-72	70-72	65-73
Location and STORET No. Mo. R. nr Williston, N.D., [illegible]																			
No. of samples	33	-	-	91	91	91 1/	-	8	13	12	-	-	-	14	-	-	14	-	91
Maximum value	22.0	-	-	8.3	95000	771	-	0.27	0.07	0.55	-	-	-	800	-	-	190.0	-	398
Minimum value	1.0	-	-	7.5	9363	216	-	0.10	0.00	0.02	-	-	-	200	-	-	60.0	-	119
Mean value	7.6	-	-	7.8	22087	451	-	0.16	0.02	0.21	-	-	-	557	-	-	129.0	-	233
Period of Record	69-70	-	-	59-70	59-70	59-70	-	69-70	69-70	69-70	-	-	-	59-62	-	-	59-62	-	59-70
Location and STORET No. [illegible], N.D., [illegible]																			
No. of samples	490	120	73	276	456	133 1/	162 2/	-	151	48	13	12	-	13	2	12	13	13	362
Maximum value	26.5	15.0	7.3	8.8	95000	610	12030	-	5.10	1.17	66.0	54.0	-	710	0.01	95.0	295.0	56.0	476
Minimum value	0	3.0	0	7.6	6720	195	0	-	0.00	0.01	11.0	8.0	-	360	0.01	10.0	87.0	20.0	110
Mean value	8.3	11.2	1.8	8.2	20339	462	556	-	0.37	0.10	36.5	22.8	-	550	0.01	43.7	172.0	39.8	226
Period of Record	57-65	59-65	59-65	57-65	57-65	62-64	59-65	-	57-65	66-69	62-68	62-68	-	62-68	62-63	62-68	62-68	62-68	57-69

Table [illegible] (Continued).

	Temp C	DO mg/l	BOD mg/l	pH units	Flow cfs	TDS mg/l	SS mg/l	T-NO3 as N mg/l	NH3 mg/l	T-PO4 as P mg/l	Pb µg/l	Cu µg/l	Dissolved Hg µg/l	F µg/l	Se µg/l	Metals Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Bismarck, N. D. [illegible]																			
No. of samples	23	23	24	23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24
Maximum value	26.5	13.4	6.8	8.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	470
Minimum value	1.0	7.8	0.0	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	160
Mean value	8.2	10.9	1.9	7.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	208
Period of Record	71-73	71-73	71-73	71-73	-	-	-	-	-	-	-	-	-	-	-	-	-	-	71-73
Location and STORET No. Bismarck, N. D. [illegible]																			
No. of samples	[illegible]	[illegible]	356	453	581	360 2/	-	-	280	24	16	16	-	11	2	13 2/	15	16	662
Maximum value	23.0	14.3	6.0	8.6	[illegible]	663	-	-	0.90	0.07	60.0	50.0	-	700	0.1	59.0	360.0	42.0	706
Minimum value	0.0	6.1	0.0	7.7	1040	260	-	-	0.00	0.01	4.0	10.0	-	460	0.01	9.0	91.0	2.0	4
Mean value	8.1	11.5	1.1	8.3	18239	425	-	-	0.24	0.06	33.6	22.0	-	519	0.2	37.3	217.0	20.4	212
Period of Record	57-73	58-73	58-73	57-72	57-66	58-71	-	-	58-66	65-69	62-71	62-71	-	62-68	62-63	63-71	62-71	62-71	57-72
Location and STORET No. Fargo, N. D. [illegible]																			
No. of samples	9	-	-	31	6	27	-	16 3/	6	28	-	-	-	28	-	2 3/	22	-	-
Maximum value	25.0	-	-	8.5	14200	484	-	0.92	0.14	0.10	-	-	-	600	-	0	470.0	-	-
Minimum value	0.0	-	-	7.6	8300	436	-	0.14	0.00	0.00	-	-	-	400	-	0	50.0	-	-
Mean value	11.1	-	-	8.0	11483	460	-	0.31	0.06	0.06	-	-	-	516	-	0	146.0	-	-
Period of Record	70-73	-	-	66-71	66-73	71-73	-	66-73	1973	71-73	-	-	-	66-73	-	1966	66-73	-	-

reports lab pH values, whereas the "inactive" (for pH)[1] EPA-USGS (NET) station at Bismarck reported field values. The different measuring procedures may explain the difference in mean pH values of 7.6 and 8.3 reported from the Bismarck stations, as may the differences in periods-of-record. The two inactive monitoring stations at Williston, North Dakota both reported period-of-record mean pH values within the range of 7.6-8.3. The maximum pH value reported from the active stations was 8.7 near Culbertson, Montana, while the minimum reported pH value was 6.8 at Bismarck, North Dakota. This range in pH values was similar to the pH range reported prior to 1970 at the two inactive stations at Williston, North Dakota.

Dissolved Oxygen

A considerable number of dissolved oxygen measurements (584) have been made since 1958 on the mainstem Missouri River between Culbertson, Montana and Pierre, South Dakota. Average dissolved oxygen concentrations at the four sampling locations gathering DO data, in downstream order, were 10.0, 11.2, 10.9 and 10.6 mg/l. The maximum and minimum concentrations (15.9 and 5.9 mg/l, respectively) were both recorded at the Williston, North Dakota location prior to 1964. Of the currently active monitoring stations reporting recent data, the EPA-USGS (NET) station at Bismarck, North Dakota reported the maximum and minimum concentrations (14.3 and 6.1 mg/l).

Total Dissolved Solids

Average TDS concentrations in the Missouri River varied little (Figure I-8.9-1). In downstream order, including values for both Williston stations, the respective mean concentrations were: 411, 451, 462, 425, and 460 mg/l (mean for River of 442 mg/l). Maximum and minimum concentrations were also fairly uniform at all stations with the highest and lowest values reported at Williston, North Dakota (771 and 195 mg/l, respectively).

Flow

Missouri River flow through North and South Dakota is controlled by two major storage reservoirs: Garrison Dam, located upstream of Bismarck, North Dakota; and Oahe Dam, located upstream of Pierre, South Dakota. Controlled discharges from these impoundments help to explain the variations in mean flow illustrated in Figure I-8.9-1. In downstream order, mean flows for the period-of-record were: 12500, 20339, 18239, and 35463 cfs, respectively. No flows were recorded by the State of North Dakota at the Bismarck sampling site. The range of flow values varies from 96000 cfs at the NET station at Williston to 1040 cfs at the NET station at Bismarck.

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[1] There were no pH values reported at the aforementioned EPA-USGS (NET) station at Bismarck for 1973.

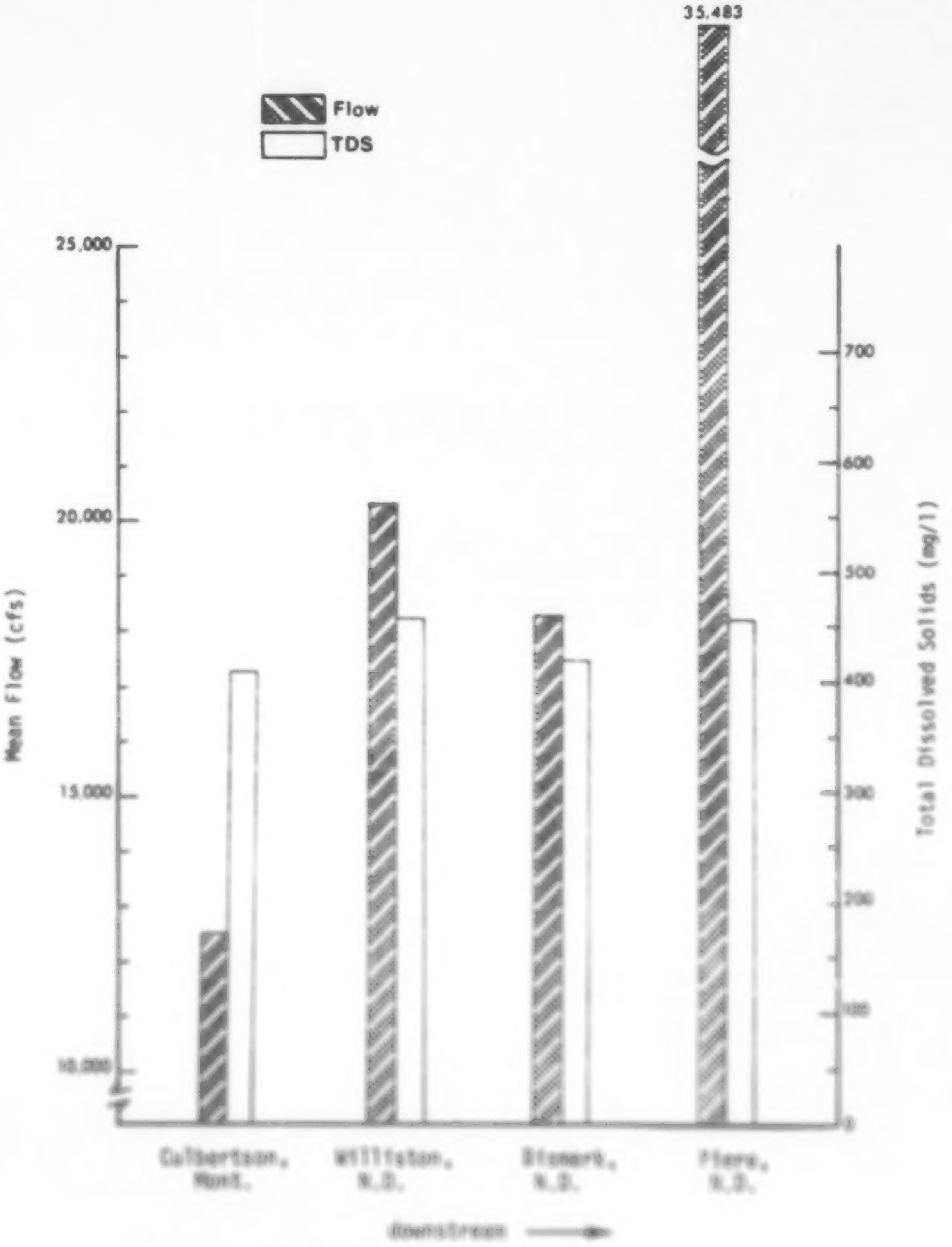

Fig. I-B.9-1 Mean flow and mean total dissolved solids for the period-of-record for selected sampling points on the Missouri River.

Trace Metals

Fluoride and boron concentrations were reported from five sampling sites with resultant mean values of approximately 575 and 150 mg/l, respectively. Data for the remaining trace metals discussed herein are the result of infrequent sampling during 1962-72. Lead, copper, and zinc were sampled approximately 30 times each during the period-of-record. The highest mean concentration reported was for lead (36 ug/l) at the NET station at Williston, North Dakota. Aluminum was measured at three different locations a total of 27 times with the highest average concentration measured 44 ug/l dissolved aluminum at Williston. The highest mean concentration of selenium was recorded at Culbertson, Montana (4.0 ug/l), while the mean mercury concentration for five measurements at Culbertson was 0.4 ug/l.

Suspended Solids

Data reported from only one location (NET station at Williston, North Dakota) showed a maximum suspended solids concentration of 12030 mg/l (Total nonfiltrable residue) between 1959-66. The mean concentration during the above period was 554 mg/l (162 measurements).

Biochemical Oxygen Demand

A total of 472 biochemical oxygen demand measurements, representing four monitoring stations, were reported. Mean concentrations were 1.1 and 1.8 mg/l at the State and the NET monitoring stations at Bismarck, North Dakota, respectively, with a mean for the River of 1.4. The maximum BOD concentration (7.1 mg/l) was recorded at Williston, North Dakota, prior to 1964.

Nutrients

Mean nitrate concentrations varied from 0.05 mg/l total nitrate (as N) at Culbertson to 0.31 mg/l dissolved nitrate (as N) at Pierre. Except for the Pierre monitoring station, there have been no nitrate analyses reported since 1970.

Ammonia concentrations have been measured at five monitoring sites. The period-of-record mean values varied from 0.02 mg/l at the USGS station at Williston to 0.37 mg/l at the NET station at Williston. The ammonia concentration of 3.1 mg/l shown in Table I-B.9-1 as the maximum concentration measured during the period-of-record at the NET station at Williston may be misleading, as the maximum recorded value for all years except 1962 was approximately 1 mg/l.

Average total phosphate concentrations over the five Missouri River monitoring sites reporting a total of 153 measurements ranged from 0.04 mg/l (Pierre and Bismarck) to 0.21 mg/l (Williston). The maximum total phosphate concentration reported was 1.17 mg/l at Williston, North Dakota.

Temperature

Maximum temperatures in the Missouri River varied from 20° to 26° C, while the mean temperature ranged from 7.4° C at Williston, North Dakota to 11.1° C at Pierre, South Dakota.

d. The Fishery

Management surveys of the Missouri River and its mainstem reservoirs, within the borders of North Dakota, have been grouped into three general areas. Area I is that portion of the river beginning at the Montana border, downstream to the Garrison Dam. Area II extends from the Garrison Dam tailrace downstream to Apple Creek, at the beginning of Lake Oahe. Area III includes the waters from Apple Creek, downstream to the South Dakota border. These areas are discussed separately because of the influence impoundment structures have had on species composition and population densities. The tables I-B.9-2 through I-B.9-8 attempt to show these changes over a twenty-year period.

Area I

Area I consists almost entirely of Lake Sakakawea, backed up behind Garrison Dam. Closure of the Garrison Dam was made in April of 1953, creating Lake Sakakawea. Lake Sakakawea filled slowly from closure to reach a peak pool of 1850.8 feet m.s.l. in 1969. The reservoir, at an elevation of 1850 feet m.s.l., has a maximum pool of 368,231 surface acres; total storage capacity of 22,855,157 acre feet; maximum depth of 180 feet; length of 200 miles; shoreline of 1600 miles, and an average width of 3 miles. Over the years, water level fluctuations within a given year have averaged less than 15 feet, but have varied to an extreme of 30 feet.

Prior to impoundment, this stretch of the Missouri ran through flat alluvial bottomlands soils. The reservoir is now surrounded by upland Regosols and grassland Chestnut soils, both moderately susceptible to erosion.

The vast watershed existing within the state is intensively farmed and grazed. Each year during periods of high runoff, erosion is significant and excessive amounts of nutrient laden silts plus organic materials are deposited in the reservoir. The presence of large algae blooms (since 1965) is evidence of the accelerated eutrophication of this reservoir.

Pre-impoundment fishery investigations on Garrison Reservoir were first undertaken in 1953-54. Sample areas were test-netted

List of fishes that have been identified in that portion of the Missouri River under investigation; or that portion within the borders of North Dakota.

Table I-B.9-2 Pre-impoundment, or initial investigations for each area.

			Year Investigated	1953 1954	(Dam to S.D. border) 1963	1962
	Common Name	Scientific Name See text for area descriptions		Area 1*	Area II*	Area III*
1.	Pallid sturgeon	Scaphirhynchus albus		—	Common	Abundant
2.	Shovelnose sturgeon	Scaphirhynchus platorynchus		—	Common	Abundant
3.	Paddlefish	Polyodon spathula		—	—	—
4.	Shortnose gar	Lepisosteus platostomus		—	Common	Rare
5.	Coho salmon	Onchorhynchus kisutch		—	—	—
6.	Rainbow trout	Salmo-gairdneri		Rare	—	—
7.	Brown trout	Salmo trutta		—	—	— —
8.	Smelt	Osmerus esperlantus		—	—	—
9.	Goldeye	Hiodon alosoides		Abundant	Abundant	Common
10.	Northern pike	Esox lucius		—	Common	Rare
11.	Carp	Cyprinus carpio		Common	Common	Common
12.	Silvery minnow	Hybognathus nuchalis		—	—	—
13.	Brassy minnow	Hybornathus hankinsoni		—	—	—
14.	Flathead chub	Hybopsis gracilis		—	—	—
15.	Golden shiner	Notemigonus crysoleucas		Abundant	—	—
16.	Emerald shiner	Notropis atherinoides		Abundant	—	—
17.	Red shiner	Notropis lutrensis		Abundant	—	—
18.	Sand shiner	Notropis stramineus		Abundant	—	—
19.	Fathead minnow	Pimephales promelas		Abundant	—	—
20.	Longnose dace	Rhinichthys cataractae		Common	—	—
21.	Creek chub	Semotilus atromaculatus		Common	—	—
22.	River carpsucker	Carpiodes carpio		Abundant	Abundant	Common
23.	Longnose sucker	Catostomus catostomus		—	—	—
24.	White sucker	Catostomus commersoni		Abundant	—	Common
25.	Blue sucker	Cycleptus elongatus		—	Rare	Rare
26.	Smallmouth buffalo	Ictiobus bubalus		—	Rare	—
27.	Bigmouth buffalo	Ictiobus cyprinellus		Rare	Rare	Rare
28.	Northern redhorse	Moxostoma macrolepidotum		Common	Common	Rare
29.	Black bullhead	Ictalurus melas		Abundant	Rare	Common
30.	Channel catfish	Ictalurus punctatus		Abundant	Abundant	Common
31.	Stonecat	Noturus flavus		—	—	—
32.	Tadpole madtom	Noturus cyrinus		—	—	Rare
33.	Flathead catfish	Phlodictis olivaris		—	Rare	Rare
34.	Burbot	Lota lota		Rare	Rare	Rare
35.	White bass	Roccus chrysops		—	Rare	—
36.	Largemouth bass	Micropterus salmoides		—	Rare	—
37.	Smallmouth bass	Micropterus dolomieui		—	—	—
38.	Green sunfish	Lepomis cyanellus		—	—	—
39.	Pumpkinseed	Lepomis gibbosus		—	—	Rare
40.	Orangespotted sunfish	Lepomis humilis		—	Rare	—
41.	Bluegill	Lepomis macrochirus		—	—	Rare
42.	White crappie	Pomoxis annularis		Rare	Abundant	Rare

Table I-B.9-2 continued

	Common Name	Scientific Name	Area 1*	Area II*	Area III*
43.	Black crappie	*Pomoxis migromaculatus*	____	Abundant	Rare
44.	Iowa darter	*Etheostoma exile*	____	____	____
45.	Johnny darter	*Etheostoma migrum*	____	____	____
46.	Yellow perch	*Perca flavescens*	Common	Common	Rare
47.	Sauger	*Stizostedion canadense*	Common	Common	Common
48.	Walleye	*Stizostedion vitreum vitreum*	Common	Rare	Rare
49.	Freshwater drum	*Aplodinotus grunniens*	Common	Rare	Rare

* Absent = None captured.

Rare = When the number of specimens captured averages 1 or less per station.

Common = When the number of specimens captured averages more than 1, but less than 11 per station.

Abundant = When the number of specimens captured averages 11 or more per station.

List of fishes that have been identified in that portion of the Missouri River under investigation; or that portion within the borders of North Dakota.

Table I-B.9-3 Approximate mid-period for investigations in each area.

		Year Investigated	1963	1965	1968
	Common Name	Scientific Name See text for area descriptions	Area 1*	Area II*	Area III*
1.	Pallid sturgeon	Scaphirhynchus albus	Rare	Rare	Rare
2.	Shovelnose sturgeon	Scaphirhynchus platorynchus	Rare	Common	Common
3.	Paddlefish	Polyodon spathula	———	———	———
4.	Shortnose gar	Lepisosteus platostomus	———	Rare	Rare
5.	Coho salmon	Onchorhynchus kisutch	———	———	———
6.	Rainbow trout	Salmo-gairdneri	———	———	———
7.	Brown trout	Salmo trutta	———	———	———
8.	Smelt	Osmerus esperlantus	———	———	———
9.	Goldeye	Hiodon alosoides	Abundant	Common	Abundant
10.	Northern pike	Esox lucius	Common	Common	Common
11.	Carp	Cyprinus carpio	Abundant	Common	Common
12.	Silvery minnow	Hybognathus nuchalis	———	Rare	———
13.	Brassy minnow	Hybognathus hankinsoni	———	———	———
14.	Flathead chub	Hybopsis gracilis	———	———	———
15.	Golden shiner	Notemigonus crysoleucas	———	———	Common
16.	Emerald shiner	Notropis atherinoides	———	———	———
17.	Red shiner	Notropis lutrensis	———	———	———
18.	Sand shiner	Notropis stramineus	———	———	———
19.	Fathead minnow	Pimephales promelas	———	———	———
20.	Longnose dace	Rhinichthys cataractae	———	———	———
21.	Creek chub	Semotilus atromaculatus	———	———	———
22.	River carpsucker	Carpiodes carpio	Common	Common	Common
23.	Longnose sucker	Catostomus catostomus	———	———	———
24.	White sucker	Catostomus commersoni	Common	Rare	Rare
25.	Blue sucker	Cycleptus elongatus	Rare	———	Common
26.	Smallmouth buffalo	Ictiobus bubalus	Rare	Rare	———
27.	Bigmouth buffalo	Ictiobus cyprinellus	Rare	Rare	Common
28.	Northern redhorse	Moxostoma macrolepidotum	Rare	Rare	Common
29.	Black bullhead	Ictalurus melas	Abundant	Rare	Common
30.	Channel catfish	Ictalurus punctatus	Common	Rare	Common
31.	Stonecat	Noturus flavus	———	———	———
32.	Tadpole madtom	Noturus cyrinus	Rare	———	———
33.	Flathead catfish	Pylodictis olivaris	———	———	———
34.	Burbot	Lota lota	Rare	———	Rare
35.	White bass	Roccus chrysops	———	———	Abundant
36.	Largemouth bass	Micropterus salmoides	———	———	———
37.	Smallmouth bass	Micropterus dolomieui	———	———	———
38.	Green sunfish	Lepomis cyanellus	———	———	———
39.	Pumpkinseed	Lepomis gibbosus	———	———	Rare
40.	Orangespotted sunfish	Lepomis humilis	———	———	Rare
41.	Bluegill	Lepomis macrochirus	———	———	Common
42.	White crappie	Pomoxis annularis	Abundant	Common	Abundant

Table I-B.9-3 continued

	Common Name	Scientific Name	Area 1*	Area II*	Area III*
43.	Black crappie	*Pomoxis migromaculatus*	Abundant	Common	Abundant
44.	Iowa darter	*Etheostoma exile*	Abundant	Common	Abundant
45.	Johnny darter	*Etheostoma migrum*	—	—	—
46.	Yellow perch	*Perca flavescens*	Abundant	Rare	Abundant
47.	Sauger	*Stizostedion canadense*	Abundant	Common	Common
48.	Walleye	*Stizostedion vitreum vitreum*	Common	Rare	Common
49.	Freshwater drum	*Aplodinotus grunniens*	Common	Rare	Common

* Absent = None captured.

Rare = When the number of specimens captured averages 1 or less per station.

Common = When the number of specimens captured averages more than 1, but less than 11 per station.

Abundant = When the number of specimens captured averages 11 or more per station.

List of fishes that have been identified in that portion of the Missouri River under investigation; or that portion within the borders of North Dakota.

Table I-B.9-4 The most recent investigations for each area.

		Year Investigated	1972	1968	1973
	Common Name	Scientific Name See text for area descriptions	Area 1*	Area II*	Area III*
1.	Pallid sturgeon	Scaphirhynchus albus	Rare	—	Abundant
2.	Shovelnose sturgeon	Scaphirhynchus platorynchus	—	Abundant	Common
3.	Paddlefish	Polyodon spathula	Rare	—	Rare
4.	Shortnose gar	Lepisosteus platostomus	—	—	Rare
5.	Coho salmon	Onchorhynchus kisutch	Rare	—	—
6.	Rainbow trout	Salmo-gairdneri	Rare	—	—
7.	Brown trout	Salmo trutta	—	—	—
8.	Smelt	Osmerus esperlantus	Rare	—	—
9.	Goldeye	Hiodon alosoides	Abundant	Common	Abundant
10.	Northern pike	Esox lucius	Common	Common	Rare
11.	Carp	Cyprinus carpio	Common	Rare	Common
12.	Silvery minnow	Hybognathus nuchalis	Abundant	Rare	Abundant
13.	Brassy minnow	Hybognathus hankinsoni	Common	—	—
14.	Flathead chub	Hybopsis gracilis	—	—	—
15.	Golden shiner	Notemigonus crysoleucas	Rare	—	Common
16.	Emerald shiner	Notropis atherinoides	—	—	—
17.	Red shiner	Notropis lutrensis	—	—	—
18.	Sand shiner	Notropis stramineus	—	—	—
19.	Fathead minnow	Pimephales promelas	Common	—	Rare
20.	Longnose dace	Rhinichthys cataractae	—	—	—
21.	Creek chub	Semotilus atromaculatus	Rare	—	—
22.	River carpsucker	Carpiodes carpio	Common	Abundant	Common
23.	Longnose sucker	Catostomus catostomus	—	—	—
24.	White sucker	Catostomus commersoni	Abundant	Rare	Rare
25.	Blue sucker	Cycleptus elongatus	Rare	Common	Common
26.	Smallmouth buffalo	Ictiobus bubalus	Rare	—	Common
27.	Bigmouth buffalo	Ictiobus cyprinellus	Common	Rare	Common
28.	Northern redhorse	Moxostoma macrolepidotum	Common	Common	Common
29.	Black bullhead	Ictalurus melas	Rare	Common	Abundant
30.	Channel catfish	Ictalurus punctatus	Abundant	Common	Common
31.	Stonecat	Noturus flavus	Common	—	Rare
32.	Tadpole midtom	Noturus cyrinus	—	—	—
33.	Flathead catfish	Pylodictis olivaris	—	—	—
34.	Burbot	Lota lota	Rare	—	Rare
35.	White bass	Roccus chrysops	Common	—	Abundant
36.	Largemouth bass	Micropterus salmoides	—	—	Rare
37.	Smallmouth bass	Micropterus dolomieui	Rare	—	Common
38.	Green sunfish	Lepomis cyanellus	—	—	—
39.	Pumpkinseed	Lepomis gibbosus	—	—	—
40.	Orangespotted sunfish	Lepomis humilis	—	Rare	—
41.	Bluegill	Lepomis macrochirus	Rare	—	Rare
42.	White crappie	Pomixis annularis	Common	Abundant	Abundant

Table I-B.9-4 continued

Common Name	Scientific Name	Area I*	Area II*	Area III*
43. Black crappie	*Pomoxis migromaculatus*	Common	Abundant	Abundant
44. Iowa darter	*Etheostoma exile*	—	—	—
45. Johnny darter	*Etheostoma migrum*	Rare	—	—
46. Yellow perch	*Perca flavescens*	Abundant	Rare	Common
47. Sauger	*Stizostedion canadense*	Abundant	Rare	Common
48. Walleye	*Stizostedion vitreum vitreum*	Abundant	Common	Common
49. Freshwater drum	*Aplodinotus grunniens*	Common	Rare	Abundant

* Absent = None captured.

Rare = When the number of specimens captured averages 1 or less per station.

Common = When the number of specimens captured averages more than 1, but less than 11 per station.

Abundant = When the number of specimens captured averages 11 or more per station.

Table I-8.9-5 Lake Sakakawea Temperature Profiles 3-7 August 1972.

Lake Elevation: 1 August 1972 Midnight 1849.1 ft. msl. 8 August 1972 Midnight 1848.8 ft. msl.

-0.3 ft. msl.

Depth Meters	Williston	Little Knife Bay	Bear Den Bay	Van Hook Arm	Deep-water Bay	Charging Eagle Bay	Red Butte Bay	Nishu Bay	Beaver Bay	Douglas Bay	Sasakawea Bay	Wolf Creek Bay
Air	22.1	23.1	20.6	21.0	19.5	18.0	19.6	19.5	16.3	19.3	15.7	23.5
Surface	21.3	22.4	21.7	20.5	20.1	20.4	19.9	20.1	18.0	20.0	19.4	21.9
1	20.9	21.6	21.5	20.5	20.1	20.5	20.0	20.5	19.5	20.3	19.6	20.8
2	20.5	20.9	21.3	20.2	20.1	20.5	20.0	20.4	19.8	20.5	19.6	20.2
3	19.9	20.1	20.5	20.0	20.1	20.5	20.0	20.4	20.0	20.5	19.7	20.0
4		19.8	20.3	19.9	20.1	20.5	19.8	20.4	20.1	20.5	19.7	19.8
5		19.8	20.0	19.9	20.1	20.4	19.8	20.2	20.1	20.5	19.7	19.8
6		19.6	19.8	19.9	20.1	20.4	19.8	20.2	20.1	20.5	19.8	19.6
7		19.6	19.5	19.7	20.1	20.3	19.8	20.2	20.1	20.5	19.8	19.6
8		19.6	19.3	19.7	20.1	20.2	19.8	20.2	20.1	20.5	19.8	19.6
9		19.5	19.0	19.7	20.1	20.0	19.8	20.2	20.1	20.3	19.8	19.6
10		19.4	18.9	19.6	20.1	19.8	19.8	20.2	20.0	20.1	19.8	19.5
11		19.2	18.7	19.5	20.0	19.6	19.8	20.0	20.0	20.1	19.8	19.5
12		19.0	18.7	19.9	20.0	19.5	19.8	19.8	19.8	20.0	19.5	19.5
13		19.0	18.5	18.8	19.9	19.3	19.8	19.5	19.6	19.9	19.3	19.5
14		18.6	18.6	18.5	19.9	19.0	19.8	19.3	19.5	19.5	19.1	19.4
15		18.3	18.3	18.4	19.7	18.7	19.4	19.0	19.4	19.1	19.0	19.4
16		17.7	18.1	18.1	19.7	18.5	10.0	18.5	19.1	19.0	18.8	19.4
17		17.2*	18.1	18.1	19.4	18.3	18.7	18.2	18.6	18.9	18.6	19.4
18		16.5	17.9	18.0	19.1	18.0	18.5	17.9	18.4	18.9	18.5	19.4
19		15.8	17.6	17.7	18.9	17.3	18.5	17.5	18.1	18.6	18.5	19.4
20		15.5	17.1	17.5	18.6	16.9	18.4	17.2	17.0	18.6	18.3	19.4
21		15.2	16.0	17.2	18.5	16.5	17.5	17.1	16.1	18.5	18.3	19.7
22		14.9	15.5*	16.5	18.3	16.2	16.2	17.0	15.4*	18.2	18.0	19.3
23		14.6	14.6	15.5*	17.8	15.6	15.4*	16.2*	14.6	18.0	17.7	19.3
24		14.3	14.1	14.9	17.3	14.4*	14.0	15.6	14.0	16.6*	17.5	19.1
25			13.9	14.3	16.1*	14.0	12.7	14.9	13.2	15.6	16.7	18.7
26			13.5	13.7	15.1	13.0	11.6	14.3	12.6	15.2	16.0	18.4
27			13.5	13.0	14.5	12.4	11.4	14.2	12.1	14.5	14.6	17.1*
28			13.5		14.0	11.9	11.2	13.8	11.6	13.5	12.0*	16.0
29			13.4		13.6	11.5	11.0	13.5	11.1	12.2	11.5	15.2
30			13.4		13.3	10.6	10.6	12.6	10.8	11.5	11.1	14.2
31						10.6	10.2	11.9	10.1	10.7	10.9	13.0
32						10.6	10.0		10.0	10.3	10.6	11.5
33						10.6	10.0		10.0	10.0	10.5	11.3
34							10.0		10.0	9.9	10.5	10.9
35							9.9		10.0	9.5	10.4	10.5
36									10.0	9.4	10.2	10.1
37									10.0	9.4	10.2	10.0
38									10.0	9.4	10.0	9.9
39									9.9	9.4	9.6	9.6
40									9.7	9.2	9.6	9.5
41											9.5	9.4
42											9.5	9.4
43											9.5	9.2
44											9.5	9.2
45											9.5	9.2
46											9.0	8.6
47												8.6
48												8.6
49												8.6
50												8.5
51												8.5
52												8.4
53												8.4

* Thermocline temp.

Table I-B.9-6

LAKE SAKAKAWEA

3-7 August 1972

Lake Data Sheet

Station	Depth(m)	Temp°C	D.O.	PH.	Iron Total	Iron Ferrous	Nitrogen Nitrite	Nitrogen Nitrate	Alkalinity Phth.	Alkalinity Total	Hardness Total	Conductivity
Williston Bay	2m	20.5	8.8	7.621	0.30	0.30	0.0186	3.5	0	140	204	453.0
Little Knife Bay	Sur.	22.4	10.2	7.641	0.000	----	0.0006	2.9	0	118	164	418.0
Little Knife Bay	17m	17.2	7.4	7.556	0.000	----	0.0000	0.0	0	138	180	453.0
Little Knife Bay	23m	14.6	6.2	7.512	0.08	----	0.0034	4.2	0	140	194	488.0
Bear Den Bay	Sur.	21.7	10.0	7.694	0.000	----	0.0020	4.5	0	122	164	418.0
Bear Den Bay	22m	15.5	6.8	7.434	0.060	3.045	0.0036	3	0	132	190	488.0
Bear Den Bay	28m	13.5	6.4	7.455	0.086	0.070	0.0038	3.1	0	136	196	496.8
Van Hook Arm	Sur.	20.5	10.0	7.648	0.000	----	0.0010	2.3	0	131	186	479.2
Van Hook Arm	23m	15.5	7.0	7.469	0.054	0.050	0.0068	6	0	142	200	505.5
Van Hook Arm	26m	13.7	6.8	7.425	0.098	0.066	0.0052	6.9	0	138	202	505.5
Deepwater Bay	Sur.	20.1	8.4	7.741	0.080	0.028	0.0096	5.1	0	130	198	496.8
Deepwater Bay	25m	16.1	7.4	7.508	0.064	0.064	0.0104	5.9	0	138	200	488.0
Deepwater Bay	28m	14.0	6.8	7.455	0.042	0.025	0.0110	9	0	142	202	505.5
Charging Eagle Bay	Sur.	20.4	9.0	7.665	0.022	0.000	0.0098	2	0	140	202	523.0
Charging Eagle Bay	24m	14.4	7.8	7.516	0.022	0.012	0.0057	1.8	0	138	202	523.0
Charging Eagle Bay	30m	10.6	7.2	7.452	0.014	0.000	0.0014	3.8	0	140	202	514.2
Red Butte Bay	Sur.	19.9	8.4	7.714	0.028	0.000	0.0132	2	0	140	204	531.6
Red Butte Bay	23m	15.4	8.0	7.572	0.042	0.030	0.0080	4	0	136	202	531.6
Red Butte Bay	30m	10.5	8.2	7.452	0.062	0.029	0.0005	4	0	142	200	523.0
Nishu Bay	Sur.	20.4	9.6	7.751	0.033	0.033	0.0088	2.3	0	142	206	531.6
Nishu Bay	23m	16.2	8.6	7.553	0.048	0.048	0.0042	4.6	0	142	206	531.6
Nishu Bay	28m	13.8	8.0	7.532	0.021	0.010	0.0028	3.3	0	140	208	523.0
Beaver Bay	Sur.	18.0	9.8	7.675	0.066	0.020	0.0118	3.6	0	142	206	540.2
Beaver Bay	22m	15.4	8.2	7.547	0.029	0.027	0.0034	3	0	138	208	531.6
Beaver Bay	38m	10.0	8.2	7.480	0.042	0.025	0.0008	3.3	0	142	208	531.6
Douglas Bay	Sur.	20.0	9.4	7.751	0.022	0.022	0.0076	5.2	0	146	206	523.0
Douglas Bay	24m	16.6	9.0	7.596	0.054	0.025	0.0052	3.7	0	146	206	523.0
Douglas Bay	38m	9.4	9.0	7.433	0.030	0.028	0.0032	3	0	146	214	531.6
Sakakawea Bay	Sur.	19.4	8.8	7.692	0.057	0.036	0.0136	5	0	142	208	531.6
Sakakawea Bay	28m	12.0	8.6	7.542	0.039	0.004	0.0054	4.3	0	144	214	531.6
Sakakawea Bay	45m	9.5	10.0	7.480	0.048	0.048	0.0068	3.3	0	148	212	540.2
Wolf Creek Bay	Sur.	21.9	7.8	7.735	0.033	0.033	0.0084	6.2	0	140	206	531.6
Wolf Creek Bay	27m	17.1	7.4	7.570	0.022	0.004	0.0024	4.7	0	144	206	540.2
Wolf Creek Bay	49m	8.6	8.6	7.518	0.028	0.024	0.0052	2.2	0	148	210	540.2

Table I-B.9-7 Lake Sakakawea Temperature Profiles July 31 - August 1, 1973

Lake Elevation: 31 July 1973 1848.7 ft. msl.

Meters	Williston	Tobacco Garden	Little Knife Bay	Bear Den Bay	Van Hook Arm	Deep-water Bay	Charging Eagle Bay	Red Butte Bay	Nishu Bay	Beaver Bay	Douglas Bay	Sakakawea Bay	Wolf Creek Bay
Air	25.0+	24.3	23.0	18.4	22.5	22.0	22.5	23.6	24.5	22.2	21.8	21.5	18.8
Surface	25.0+	23.3	20.7	20.7	21.5	23.3	21.0	20.5	20.1	20.3	19.5	19.5	19.5
1	22.5	22.8	20.5	20.7	21.5	22.5	20.8	20.5	19.8	20.1	19.5	19.5	19.5
2	19.8*	22.5	20.5	20.5	20.5	20.5	20.8	20.2	19.6	20.1	19.3	19.5	19.5
3		22.0	20.3	20.5	20.5	20.5	20.6	20.2	19.5	20.0	19.3	19.5	19.5
4		21.8	20.3	20.5	20.3	20.5	20.3	20.0	19.5	19.8	19.1	19.5	19.5
5		21.5	20.3	20.3	20.0	20.3	20.1	19.8	19.4	19.8	19.1	19.5	19.5
6		21.2	20.1	20.3	20.0	20.0	20.0	19.8	19.4	19.6	19.6	19.5	19.5
7		21.0*	20.0	20.2	20.0	19.8	19.7	19.5	19.2	19.5	19.5	19.5	19.5
8		20.7	19.5	20.2	19.8	19.8	19.7	19.5	19.2	19.3	18.7	19.5	19.5
9		20.5	19.1	20.2	19.8	19.5	19.5	19.1	19.2	19.3	18.7	19.3	19.5
10		20.2	18.7	20.0	19.4	19.3	19.5	19.0	19.2	19.3	18.5	19.3	19.3
11		20.2	18.5	20.0	19.0	19.3	19.3	18.8	19.0	19.1	18.5	19.1	19.3
12		20.0	18.5	20.0	18.8	19.0	19.0	18.8	19.0	19.1	18.3	19.1	19.3
13		20.0	18.2	19.8	18.5	18.7	18.8	18.6	19.0	19.0	18.3	19.0	19.2
14		20.0	18.0	18.6	18.2	18.2	18.6	18.6	19.0	19.0	18.3	19.0	19.2
15			17.0	16.3*	17.6	17.2*	18.3	18.5	19.0	18.8	18.3	19.0	19.1
16			16.5*	15.3	17.3	16.6	18.1	18.5	18.8	18.6	18.0	18.7	19.0
17			15.2	14.5	16.1*	16.3	17.8	18.1	18.8	18.5	17.7	18.5	18.7
18			14.9	14.1	16.0	16.0	17.0	17.1	17.4*	16.4*	17.7	18.5	18.3
19			14.7	13.6	15.1	16.0	15.8	15.9	16.8	16.0	17.7	18.2	17.9
20			14.7	13.5	14.6	15.7	14.2*	14.5*	16.5	15.1	17.7	18.2	17.6
21			14.5	13.3	14.4	15.2	13.5	13.4	16.5	14.6	17.5	18.0	17.4
22			14.3	13.3	14.0	14.5	13.2	12.8	16.0	14.2	17.5	17.1	16.5
23			14.3	13.2	13.5	14.0	12.9	12.5	15.7	13.8	17.3	15.5*	15.6
24			14.0	13.1	13.2	13.3	12.6	12.2	15.3	13.5	17.3	15.2	15.4
25			14.0	13.1	13.2	13.3	12.5	12.0	14.9	12.7	17.1	14.5	14.5
26				13.0	13.0	13.3	12.3	12.0	14.5	12.5	16.3*	14.2	13.6
27				13.0	12.8	13.0	12.3	11.7	13.7	12.1	16.3	13.6	13.2*
28					12.5	13.0	12.3	11.5	11.8	11.8	15.7	13.1	12.0
29					12.2	13.0	12.1	11.5		11.8	15.5	13.0	11.8
30						12.6	12.0	11.5		11.5	15.0	12.7	11.7
31								11.3		11.5	14.3	12.5	11.7
32								11.3		11.5	14.1	12.1	11.5
33										11.5	12.8	12.0	11.4
34										11.3	12.5	12.0	11.2
35										11.3		11.7	11.0
36										11.3		11.5	10.8
37										11.3		11.3	10.6
38										11.2		11.3	10.6
39										10.9		11.1	10.6
40												11.0	10.5
41												11.0	10.5
42												10.8	10.5
43												10.6	10.3

* Thermocline temp.

Table I-8.9-8

LAKE SAKAKAWEA

July 31 - August 1, 1973

Lake Data Sheet

Station	Depth(m)	Temp°C.	D.O.	PH.	Iron Total	Iron Ferrous	Nitrogen Nitrite	Nitrogen Nitrate	Alkalinity Phth.	Alkalinity Total	Hardness Total	Conductivity	Ortho Phosphate	Turbidity JTU	Secchi Disk(M)
Williston Bay	2.0	19.8	7.8	8.23	0.200	0.170	0.000	4.5	0	7.3	238	400	.15	117	.25
Tobacco Garden Bay	Sur.	23.3	8.8	8.10	0.100	0.030	0.004	5.0	0	6.8	198	325	.08	10	.6
Tobacco Garden Bay	7.0	21.0	7.6	7.88	0.270	0.110	0.010	8.0	0	6.0	154	260	.08	20	
Tobacco Garden Bay	14	20.0	7.8	7.90	0.310	0.100	0.001	5.0	0	6.1	162	265	.10	42	
Little Knife Bay	Sur.	20.7	8.6	8.10	0.080	0.020	0.001	4.0	0	6.5	182	295	.09	11	—
Little Knife Bay	16	16.5	5.2	8.05	0.130	0.040	0.000	4.5	0	7.6	218	355	.12	17	1.5
Little Knife Bay	25	14.0	5.4	7.88	0.230	0.050	0.005	3.0	0	7.7	224	355	.18	61	
Bear Den Bay	Sur.	20.7	8.2	7.81	0.200	0.090	0.011	8.0	0	5.8	158	260	.13	21	—
Bear Den Bay	15	16.3	8.4	8.09	0.100	0.020	0.003	3.0	0	7.1	212	335	.09	10	1.9
Bear Den Bay	27	13.0	8.0	8.01	0.100	0.010	0.000	3.5	0	7.7	224	350	.12	21	
Van Hook Arm	Sur.	21.5	8.6	7.92	0.030	0.000	0.006	7.0	0	7.9	234	345	.10	9	—
Van Hook Arm	17	16.1	7.4	8.15	0.060	0.000	0.000	3.0	0	7.8	224	355	.09	10	3.2
Van Hook Arm	29	12.2	6.0	7.41	0.220	0.080	0.010	10.0	0	7.8	216	345	.12	31	
Deepwater Bay	Sur.	23.3	8.8	8.09	0.060	0.030	0.006	8.0	0	7.7	226	360	.08	5	—
Deepwater Bay	15	17.2	7.8	8.12	0.030	0.000	0.001	5.5	0	7.8	220	355	.10	7	3.0
Deepwater Bay	30	12.6	7.0	8.03	0.100	0.020	0.001	2.0	0	7.7	220	345	.10	35	
Charging Eagle Bay	Sur.	21.0	8.6	8.01	0.045	0.000	0.003	5.0	0	7.7	226	360	.09	12	—
Charging Eagle Bay	20	14.2	8.4	7.98	0.100	0.080	0.006	4.0	0	7.6	210	340	.10	14	2.5
Charging Eagle Bay	30	12.0	7.0	7.90	0.200	0.060	0.000	7.5	0	7.7	214	340	.10	65	
Red Butte Bay	Sur.	20.5	8.4	8.01	0.030	0.000	0.000	6.0	0	7.7	230	360	.13	10	—
Red Butte Bay	20	14.5	8.2	8.00	0.010	0.010	0.000	4.0	0	7.6	216	345	.09	10	2.2
Red Butte Bay	32	11.3	8.0	7.32	7.070	0.020	0.000	7.0	0	7.5	214	345	.15	21	
Nishu Bay	Sur.	20.1	9.2	8.06	0.100	0.080	0.003	4.0	0	7.6	220	350	.10	9	—
Nishu Bay	18	17.4	9.0	8.01	0.060	0.030	0.003	9.0	0	7.8	224	350	.09	11	4.0
Nishu Bay	28	11.8	8.6	7.83	0.070	0.040	0.000	3.0	0	7.6	214	340	.06	27	
Beaver Bay	Sur.	20.3	9.2	8.01	0.000	0.000	0.000	6.0	0	7.8	222	351	.09	10	—
Beaver Bay	18	16.4	8.8	8.02	0.060	0.020	0.002	5.5	0	7.7	220	350	.10	7	3.5
Beaver Bay	39	10.9	8.6	7.35	0.145	0.080	0.001	4.5	0	7.5	202	330	.10	21	
Douglas Bay	Sur.	19.5	8.8	8.02	0.060	0.020	0.003	10.0	0	7.6	216	340	.07	7	—
Douglas Bay	26	16.3	8.8	7.99	0.010	0.010	0.002	4.5	0	7.4	210	335	.04	11	2.8
Douglas Bay	34	12.5	9.0	7.99	0.025	0.010	0.003	6.0	0	7.6	214	340	.12	15	
Sakakawea Bay	Sur.	19.5	9.2	8.02	0.000	0.000	0.002	8.0	0	7.5	200	330	.07	8	—
Sakakawea Bay	23	15.5	9.2	7.92	0.080	0.080	0.008	5.0	0	7.5	208	330	.04	9	3.0
Sakakawea Bay	43	10.6	8.8	7.85	0.080	0.000	0.000	5.0	0	7.2	202	325	.10	12	
Wolf Creek Bay	Sur.	19.5	8.8	7.90	0.010	0.000	0.000	10.0	0	7.2	210	330	.10	8	—
Wolf Creek Bay	27	13.2	8.8	7.91	0.030	0.030	0.000	6.5	0	7.3	200	325	.05	9	4.0+
Wolf Creek Bay	43	10.3	9.2	7.89	0.045	0.020	0.000	6.0	0	7.2	208	325	.10	10	—

and seined when possible. Other sources of information for those early years included annual commercial fishery questionnaires. Over the past twenty years a number of species have shared the spotlight as being the most important. In those early years, channel catfish and black bullheads ranked number one to the angler and commercial fisherman. As the reservoir filled, spawning habitats changed and new species took the number one position of importance. The late 50's and early 60's had perch ranked very high. In the early through mid 60's, northern pike and sauger reached their peak and provided an excellent fishery. Fluctuating water levels and erosion continued to change spawning habitats. For the 70's, one would have to rate the walleye as providing the most important fishery. These isolated examples only touch upon the many changes that have taken place in species composition and population densities.

Water quality investigations on the Missouri have been limited. In 1972-3, investigations were undertaken to characterize primary production through the physical and chemical attributes existing along the 200 mile length of the reservoir. Summaries of the physical and chemical characteristics sampled in 1972 and 1973 at various locations are given in Tables I-B.9-5 through I-B.9-8.

The sport and commercial fishery on the Missouri River has had its ups and downs over the past twenty years. Tables I-B.9-2 through I-B.9-4 show these trends for the three study areas. It should be noted that because of the many changes in investigation techniques, these tables can be used only as a rough guide.

The number of sampling stations for the three areas ranged from 2 to 25.

Area II

Area II contains the River between Garrison Dam and the upper reach of Lake Oahe. This stretch of the Missouri River still runs through the bottomlands soils, once characteristic to the entire river prior to impoundments. These alluvial soils are loams and sandy loams of the Havre-Banks soil association. Alluvial fans include Chernozem and Regosol soils. The main drainages in this area are the Knife and Heart Rivers. Both of these rivers drain the Regosol and Chestnut soil groups as explained for Area I.

Area II is used primarily for summer pasture and winter feedlot operations. Pollution contributions from this area are considered excessive. The last aerial survey (January 1974) disclosed 123 feedlot operations, wintering some 19,000 head of livestock. Industrial and municipal wastes also degrade the water quality.

Limited fishery investigations have been carried out on Area II. The netting stations were established wherever conditions were favorable. Swift currents in the main channel necessitated setting all nets in back waters or adjacent to the current. Tables I-B.9-2 through I-B.9-4 give an account of the fishery division investigations.

A ten-year creel census of the Garrison Tailrace (1960-69) showed sauger to be the most abundant species, followed by walleye and northern pike. In the final two years (1968-69) of creel census, white bass and channel catfish, which had not been previously counted, represented nearly 22.0 percent of the creel. The early years of Lake Oahe development were important to the fishery that flourished in the tailrace.

Area III

Area III includes Lake Oahe and the River downstream to the South Dakota border. Closure of Oahe Dam was made in August of 1958, creating Lake Oahe. The reservoir, at an elevation of 1620 feet m.s.l., has a maximum pool covering 370,950 surface acres, and a storage capacity of 23,506,534 acre feet of water. At maximum pool, the reservoir has a length of 231 miles, shoreline of 2,250 miles and a maximum depth of 200 feet. That portion of Lake Oahe that lies within North Dakota would cover 125,300 surface acres and store 7,800,000 acre feet of water at maximum pool.

Area III is similar to Area I in that the exposed soils have changed from bottomlands soils characteristic of the river valley, to those characterized by the Regosol and Chestnut soil groups. The main drainages in this area include Apple Creek, the Cannonball River, and Beaver Creek. Principal pollution is again in the form of nutrient laden silts and organic materials which originate on feedlots and agricultural lands. In the past this has been somewhat complicated by mill tailings and metals from the Homestake Mine near Lead, South Dakota, which enter in the Cheyenne arm.

Oahe Reservoir experiences the same extreme water level fluctuations as does Garrison Reservoir. Long term trends in the fishery of Oahe Reservoir have not been as pronounced as those of Garrison, partially due to the difference in the ages of the reservoirs. The most significant changes in the fishery of Oahe have been in the panfish populations. White bass and crappies have experienced a sharp increase in population densities since 1968. The walleye is also an important species in this reservoir. Information on fish composition in Area III is given in Tables I-B.9-2 through I-B.9-4.

I-B.10

Belle Fourche River Basin

a. The Basin

The Belle Fourche River Drainage in Wyoming contains about 3,762 square miles of which 344 square miles are National Forest lands, 211 square miles are State lands and 25 square miles are other Federal lands (BLM and Devil's Tower National Monument).

The highest elevation in the Wyoming drainage area is Warren Peak (6,645 ft.) and the lowest (3,100 ft.) is where the Belle Fourche enters South Dakota. This latter elevation is also the lowest point in the State of Wyoming. The topography ranges from rolling grasslands and sage brush to the mountainous forest lands of ponderosa pine contained in the Black Hills National Forest.

b. Activities Influencing Water Quality

The majority of the drainage area is used for grazing of livestock. Dry farm grains and hay crops are grown; however, crops below Keyhole Reservoir are usually irrigated by sprinkler pumping stations out of the Belle Fourche River. Other industries include oil production, logging, strip coal mining and bentonite mining.

c. Water Quality

Current water quality data in the Belle Fourche River is based on reported values from four active USGS monitoring stations and one minor infrequently sampled EPA-USGS (NET) station. The NET station is located at the Wyoming-South Dakota state line, as is the USGS monitoring station (Table I-B.10-1). A brief history of several selected water quality parameters for the period-of-record at each sampling site is presented in the following sections.

pH

Average pH values in the Belle Fourche River were approximately 7.7 standard units at the four stations reporting pH data. The pH values ranged from a minimum of 6.5 at Elm Springs to a maximum of 9.0, also at Elm Springs. There does not appear to have been a pH problem in the Belle Fourche River.

Dissolved Oxygen

Dissolved oxygen data were reported from only the State Line and Elm Springs sites, with mean values of 9.7 and 9.2 mg/1, respectively. The Elm Springs monitoring station reported the widest range of dissolved oxygen concentrations (4.8 to 12.9 mg/1). Based on an analysis of all reported data, there does not appear to have been a significant oxygen depletion problem in the Belle Fourche River.

Table I-8.10-1. Water quality data summary from selected stations on the Belle Fourche River.

													Dissolved Metals						
	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Belle Fourche River at Devils Tower 06427850																			
No. of samples	56	-	-	58	46	59	-	6 [4]	-	-	-	-	-	59	-	-	60	-	58
Maximum value	24.5	-	-	8.3	527	1750	-	.09	-	-	-	-	-	900	-	-	250.0	-	1140
Minimum value	0.0	-	-	7.4	6	449	-	.02	-	-	-	-	-	300	-	-	20.0	-	255
Mean value	9.8	-	-	7.8	59	1183	-	.05	-	-	-	-	-	600	-	-	149.3	-	745
Period of Record	67-73	-	-	67-73	68-73	67-73	-	68	-	-	-	-	-	67-73	-	-	67-73	-	67-73
Location and STORET No. Belle Fourche River at Wyo-S.Dak. St.Line 06428500 - EPA																			
No. of samples	-	-	-	-	-	-	-	3	-	3	3	3	-	-	-	-	-	3	-
Maximum value	-	-	-	-	-	-	-	0.88	-	0.16	18.0	12.0	-	-	-	-	-	10.0	-
Minimum value	-	-	-		-	-	-	0.05	-	0.08	6.0	6.0	-	-	-	-	-	12.0	-
Mean value	-	-	-	-	-	-	-	0.34	-	0.11	11.3	9.3	-	-	-	-	-	11.3	-
Period of Record	-	-	-	-	-	-	-	72-73	-	72-73	72-73	72-73	-	-	-	-	-	72-73	-
Location and STORET No. Belle Fourche River at Wyo. - S.Dakota 06428500 - USGS																			
No. of samples	55	13	12	193	182	121	2	69 [4]	8	8	7	7	6 [6]	182	8	2	188	6	181
Maximum value	28.3	12.7	4.2	8.6	917	2450	510	0.92	0.75	0.88	40.0	14.0	0.5	1100	70.0	90.0	470.0	140.0	1550
Minimum value	0.0	7.5	0.8	6.6	3	428	218	0	0.00	0.02	1.0	2.0	0.2	70	0.0	57.0	0.0	10.0	235
Mean value	10.8	9.7	1.7	7.8	111	1190	364	0.13	0.14	0.35	12.6	4.7	0.3	770	13.9	73.5	158.4	56.7	751
Period of Record	60-73	70-73	70-73	60-73	60-73	67-73	60	67-71	70-72	70-72	70-72	70-72	70-72	60-73	70-72	70-71	60-73	70-72	60-73

Table I-8.10-1 (contin.).

	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Dissolved Hg µg/l	F µg/l	Se µg/l	Metals Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Belle Fourche River near Sturgis, S. D. 06437000																			
No. of samples	51	-	-	102	90	63	3	55	-	38	4	4	1 6/	75	4	3	100	2	102
Maximum value	27.0	-	-	8.1	2830	3240	20200	15.0	-	1.70	1.0	70.0	0.3	8400	8.0	300.0	2000.0	20.0	1900
Minimum value	0.0	-	-	6.9	7	466	217	0.00	-	0.01	0.0	0.0	0.3	300	2.0	10.0	85.0	12.0	300
Mean value	10.6	-	-	7.6	376	1709	8319	2.76	-	0.36	0.3	26.8	0.3	700	5.0	170.0	321.9	16.0	926
Period of Record	60-73	-	-	59-73	59-73	69-73	1960	68-71	-	70-73	59-70	70-72	72	59-73	70-72	70-72	59-73	70	59-73
Location and STORET No. Belle Fourche near Elm Springs 06438000																			
No. of samples	82	26	25	91	117	68 1/	13	28	38	41	13	13	5	48	-	4	39	13	72
Maximum value	29.0	12.9	16.0	9.0	8560	4820	13600	8.40	0.72	3.3	11.0	80.0	0.3	2700	-	179.0	710.0	40.0	2440
Minimum value	0.0	4.8	.2	6.5	2.8	512	7	0.11	0.01	0.0	0.0	5.0	0.0	300	-	0.0	80.0	0.0	300
Mean value	9.7	9.2	3.3	7.7	361	2071	1537	3.25	0.24	0.53	0.9	34.2	0.1	608	-	114.5	342.2	18.9	1110
Period of Record	59-73	69-71	69-71	59-73	59-73	59-73	59-60	69-72	69-73	69-73	69-72	69-72	70-71	59-73	-	70-72	59-72	69-72	59-73

Total Dissolved Solids

For the period-of-record data, a generally upward trend in TDS concentrations was observed in the downstream direction for the Belle Fourche River. The upstream sampling site at Devil's Tower, Wyoming reported a mean TDS concentration of 1183 mg/l, while the downstream location at Elm Springs reported a mean concentration of 2071 mg/l. The minimum concentration occurred at the State Line sampling site (428 mg/l) while the maximum value occurred at the Elm Springs location (4830 mg/l). Flow and TDS data are shown in Figure I-B.10-1.

Flow

The Belle Fourche River exhibits a typical seasonal flow pattern; midwinter flows are often less than 10 cfs, while spring and summer flows have been recorded as high as 8560 cfs at Elm Springs, South Dakota. Mean flows varied from 59 cfs at Devil's Tower, Wyoming to 376 cfs near Sturgis, South Dakota (Figure I-B.10-1).

Trace Metals

Approximately twenty-five analyses each for lead, copper, and zinc have been conducted on water samples from four locations on the Belle Fourche River. The highest mean concentration at any of the four locations for each metal was: lead-12.6 ug/l at the USGS State Line location, copper-34.2 ug/l at Elm Springs, and zinc-56.7 ug/l at the USGS State Line location. Aluminum, selenium, and mercury concentrations in the Belle Fourche River have been measured a combined total of 33 times (three stations reporting) since 1970. Average concentrations for all reported data were: aluminum-124 ug/l, selenium-12.6 ug/l, and mercury-0.2 ug/l. Fluoride and boron concentrations in the river averaged 670 and 243 ug/l, respectively with little variation among stations.

Suspended Solids

Only 18 measurements for suspended solids have been made on the Belle Fourche River, all recorded during 1960. Most reported measurements were less than 1000 mg/l, although a few values as high as 20000 mg/l suspended solids were recorded. Stream flows higher than normal usually corresponded with the high suspended solids concentrations.

Biochemical Oxygen Demand

A total of 37 measurements for BOD have been conducted on water samples from the Belle Fourche River (State Line and Elm Springs sampling sites. Mean concentrations at the above two locations were 1.7 and 3.3 mg/l, respectively. Maximum concentrations at State Line were less than 5 mg/l, while the Elm Springs maximum concentrations were generally less than 8 mg/l, with only one exception of 16 mg/l being reported.

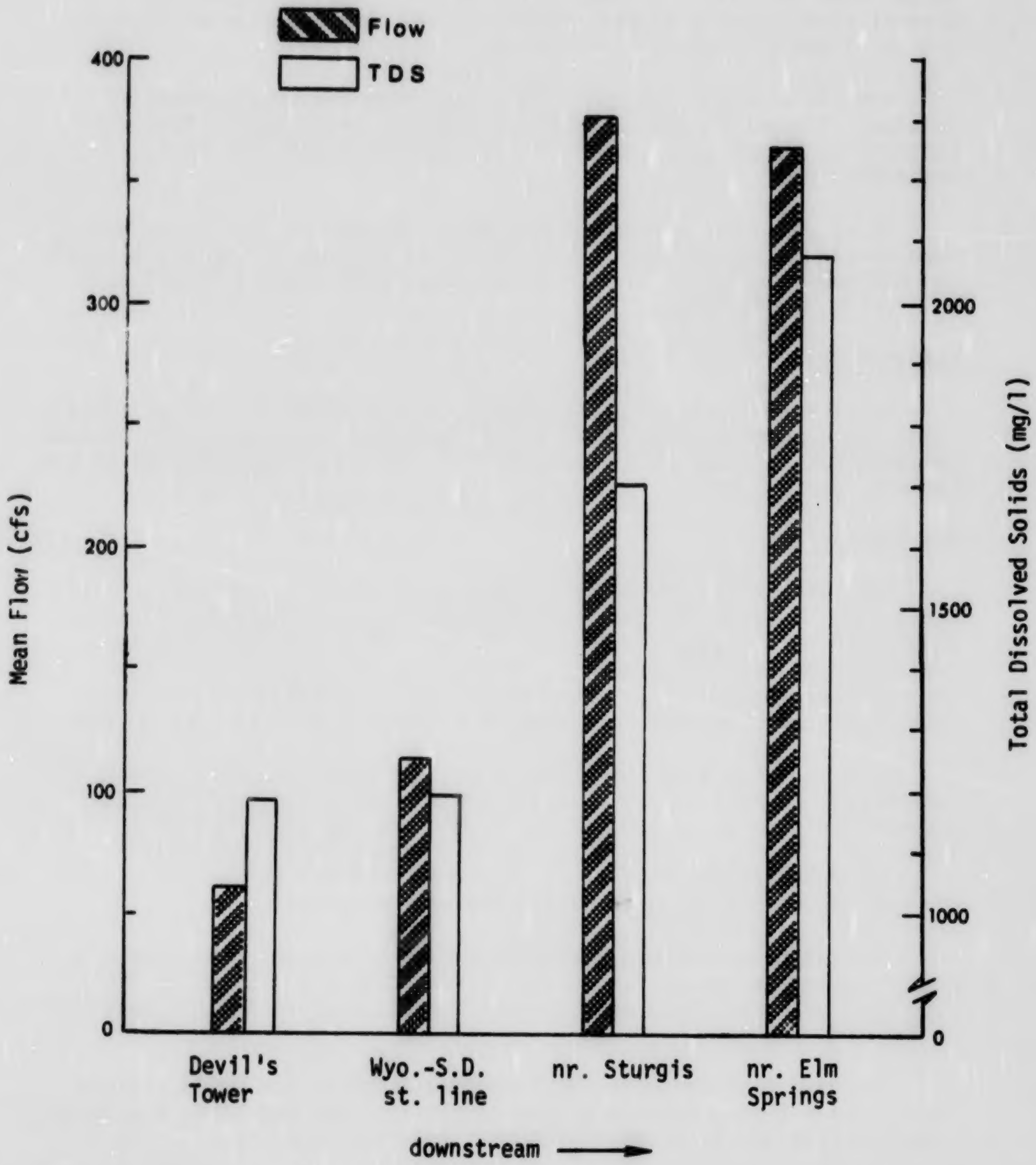

Fig. I-B.10-1 Mean flow and mean total dissolved solids for the period-of-record for selected sampling points on the Belle Fourche River.

Nutrients

A considerable number of total nitrate (NO_3) determinations (161) have been made at all five monitoring stations on the Belle Fourche River. Mean nitrate concentrations were generally higher in the downstream area near Elm Springs (3.25 mg/l T-NO_3 as N) than in the upstream area near Devil's Tower, Wyoming (0.05 mg/l T-NO_3 as N). Several significantly higher concentrations were reported at Sturgis (15 mg/l) and Elm Springs (8.4 mg/l).

Ammonia nitrogen concentrations have been measured a total of 46 times (State Line and Elm Springs stations reporting). Mean concentrations at the above two locations were 0.14 and 0.24 mg/l, respectively.

Total phosphate concentrations were measured at four sites with mean concentrations of 0.11, 0.35, 0.36 and 0.53 mg/l (Table I-B.10-1). The maximum reported total phosphate concentration was 1.7 mg/l as P at Sturgis, South Dakota.

Temperature

Average temperatures in the Belle Fourche River for the period-of-record were approximately 10° C at all sampling locations, with maximum temperatures recorded as high as 29° C at the downstream station at Elm Springs, South Dakota.

d. The Fishery

Most streams in the Belle Fourche River Drainage are not suitable for trout. Many of the streams are intermittent or have low flows in which high water temperatures and insufficient habitat are the controlling factors. A fishery can be provided on some of these small streams where beaver ponds are present; however, either flash floods or silting can eliminate this type of fishery in a short span of time.

Flow variations in the Belle Fourche are extreme above Keyhole Reservoir. In 1963 the USGS gaging station below Moorcroft recorded a maximum discharge of 1800 cfs on June 4 and zero for part of September. The water flow below Keyhole Reservoir is controlled by water releases and thus flows vary only from 273 to one cfs. Minimum flows usually occur during the winter months.

Habitat below Keyhole Reservoir varies from deep holes over six feet deep to shallow riffle areas. Beaver dams are present at times. Fish shelter varies from poor to good. Habitat above Keyhole Reservoir is less desirable.

Non-game fish dominate the fish population in the Belle Fourche River. Game fish present are channel catfish, walleye pike, bullheads, green sunfish and stonecats. The most important game fish is the channel catfish, which is found from the State Line to Keyhole Reservoir. The tailrace below Keyhole Reservoir contains populations of walleye and channel catfish, as well as bullheads and green sunfish. Other fish found include yellow perch, suckers, and carp. There have been attempts at starting smallmouth bass.

I-B.11 Cheyenne River Basin in Wyoming

a. The Basin

The Cheyenne River Drainage covers approximately 7,167 square miles in Wyoming. Public lands make up approximately 1,144 square miles of the drainage, including 587 square miles of National Forest grasslands, 387 square miles of State lands, and 170 square miles of BLM land. All of the flowing water capable of supporting significant game fish populations is on private lands.

The drainage ranges from the southern edge of the Black Hills through the rough breaks of the Rochelle Hills to rolling grass lands and high plateaus north of Lusk. Elevations range from 3,500 feet at the Wyoming-South Dakota line to 6,000 feet in the Sand Hills of Converse County. The majority of the drainage is sage brush and grass range land with some ponderosa pine in the Black Hills, Rochelle Hills, and Chalk Cliffs area.

b. Activities Influencing Water Quality

The economy of the drainage is associated with grazing of livestock, hay production, oil production, and bentonite mining. Some agricultural land used for hay production is present in the drainage. One recreational area has been developed on Stockade-Beaver Creek and Lak Reservoir.

c. Water Quality

No long term water quality stations exist in the Wyoming part of the Cheyenne Basin. A summary of current water quality information for the Cheyenne River Basin, based on data reported from three active stations and one inactive station (since 1970) on the mainstem of the Cheyenne River in South Dakota (Table I-B.11-1), has been completed. A brief history of several selected water quality parameters for the periods-of-record is presented in the following sections.

pH

Measurements of pH have been made at one or more sampling locations since 1968. The mean pH values for the period-of-record vary from 7.8 at Edgemont and Buffalo Gap to 8.1 near Wasta. The reported pH values varied from a minimum of 6.9 at Edgemont to a maximum of 9.5 near Wasta. The maximum recorded pH values at the three other sampling stations did not exceed 8.4 units. On the basis of these data, there is no pH problem in the Cheyenne River Basin.

Dissolved Oxygen

Only 25 dissolved oxygen samples were reported for the period-of-record (1969-71). Mean dissolved oxygen values were 9.2 and 10.7 mg/l

Table I-B.11-1. Water quality data summary from selected stations on the Cheyenne River.

													Dissolved			Metals			
	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
Location and STORET No. Cheyenne River at Edgemont, S.D. 06395000																			
No. of samples	44	16	13	40	43	8	-	18	26	28	8	8	3 6/	14	8	2	10	8	25
Maximum value	25.0	11.8	9.4	8.4	609	4280	-	2.00	2.40	5.80	10.0	75.0	0.3	1100	20.0	100.0	770.0	490.0	3100
Minimum value	0.0	6.1	0.5	4.2	0.3	651	-	0.00	0.00	0.00	0.0	3.0	0.1	200	0.0	0.0	10.0	20.0	250
Mean value	10.4	8.6	2.9	7.7	61	2235	-	0.44	0.35	0.49	2.1	25.5	0.2	600	5.1	50.0	346.9	132.1	1426
Period of Record	70-73	70-71	70-71	70-73	70-73	72-73	-	70-72	70-73	70-73	70-72	70-72	71-72	70-73	70-72	71-72	70-73	70-72	70-73
Location and STORET No. Cheyenne River below Angostura Dam 06401500																			
No. of samples	34	-	-	70	55	42	-	34	-	33	1	1	1	46	1	1	65	1	70
Maximum value	28.0	-	-	8.4	2060	1820	-	0.50	-	0.13	0.0	0.0	0.2	1400	9.0	151.0	860.0	10.0	960
Minimum value	0.0	-	-	7.4	0.7	962	-	0.00	-	0.00	0.0	0.0	0.2	400	9.0	151.0	40.0	10.0	410
Mean value	12.7	-	-	7.9	68	1539	-	0.11	-	0.03	0.0	0.0	0.2	700	9.0	151.0	160.4	10.0	810
Period of Record	68-73	-	-	68-73	68-73	69-73	-	68-71	-	70-73	70	70	70	69-73	70	70	68-73	70	68-73
Location and STORET No. Cheyenne River near Buffalo Gap, S.D. 06402600																			
No. of samples	37	-	-	78	62	44	-	34	-	41	-	-	-	45	-	-	72	-	78
Maximum value	26.0	-	-	8.1	8230	1930	-	1.60	-	0.90	-	-	-	1000	-	-	1750.0	-	1000
Minimum value	0.0	-	-	7.4	38	1120	-	0.00	-	0.00	-	-	-	500	-	-	140.0	-	450
Mean value	10.6	-	-	7.8	394	1679	-	0.62	-	0.10	-	-	-	611	-	-	325.7	-	854
Period of Record	68-73	-	-	68-73	68-73	69-73	-	68-71	-	70-73	-	-	-	69-73	-	-	68-73	-	68-73

Table I-8.11-1. (contin.).

													Dissolved Metals						
Location and STORET No. Cheyenne River near Wasta 06423500	Temp C	DO mg/l	BOD mg/l	pH units	flow cfs	TDS mg/l	SS mg/l	T-NO$_3$ as N mg/l	NH$_3$ mg/l	T-PO$_4$ as P mg/l	Pb µg/l	Cu µg/l	Hg µg/l	F µg/l	Se µg/l	Al µg/l	B µg/l	Zn µg/l	Total hardness mg/l
No. of samples	23	10	10	16	22	2 1/	-	10	10	10	4	4	-	4	-	-	4	4	10
Maximum value	27.0	14.0	20.0	9.5	1150	718	-	1.80	0.78	5.90	3.0	37.0	-	1400	-	-	274.0	28.0	1030
Minimum value	0.0	6.2	0.9	7.5	6	624	-	0.00	0.00	0.07	0.0	0.0	-	400	-	-	123.0	0.0	244
Mean value	8.6	10.7	3.6	8.1	654	671	-	0.78	0.35	1.48	0.8	9.6	-	800	-	-	218.5	16.8	702
Period of Record	69-70	69-70	69-70	69-70	69-70	69-70	-	69-70	69-70	69-70	69-70	69-70	-	69-70	-	-	69-70	69-70	69-70

at Edgemont and Wasta, respectively. Maximum dissolved oxygen concentrations of 11.8 and 14.0 mg/l and minimum concentrations of 6.1 and 6.2 mg/l, respectively, were reported at these two sampling locations.

Total Dissolved Solids

Average TDS concentrations in the Cheyenne River generally decreased in the downstream direction as shown in Figure I-B.11-1. The average concentration at Edgemont (upstream station) was 2235 mg/l, while the dissolved solids concentration near Wasta (downstream location) was 671 mg/l. The sampling site near Wasta, however, reported only two TDS measurements. Figure I-B.11-1 also illustrates the relation between flow and TDS observed at Edgemont and Wasta. The inverse relationship depicted is similar to other river basins. The maximum concentration of TDS was reported at Edgemont (4280 mg/l) and the minimum concentration was reported near Wasta (624 mg/l).

Flow

Mean flows in the Cheyenne River decreased uniformly in the downstream direction as shown in Figure I-B.11-1. Mean flows at reporting stations were 61, 68, 394, and 604 cfs (upstream to downstream). Spring runoff flows were as much as 20 times greater than the mean flows as reflected by the maximum recorded flows reported from the four stations -- 609, 2060, 8230, and 11500 cfs (upstream to downstream). Minimum flows of less than one cfs were occasionally reported.

Trace Metals

Limited trace metals data are available for the Cheyenne River. Only the Edgemont station reported more than four analyses for any particular metal other than fluoride and boron. Lead and copper concentrations were reported at Edgemont, below Angostura Dam, and near Wasta, with mean concentrations being less than 25 ug/l in all cases. Zinc was measured a total of 13 times at the three stations, with a mean concentration of 132 ug/l measured at Edgemont. Mercury, selenium, and aluminum maximum concentrations measured were 0.2 ug/l at Edgemont and below Angostura Dam, 20 ug/l at Edgemont, and 151 ug/l below Angostura Dam. Boron and fluoride mean concentrations for all data were approximately 275 ug/l and 700 ug/l, respectively.

Suspended Solids

There were no suspended solids data reported for the Cheyenne River sampling sites.

Biochemical Oxygen Demand

A total of 23 measurements for BOD were reported (Edgemont and Wasta). Mean BOD concentrations at the above two sampling sites were

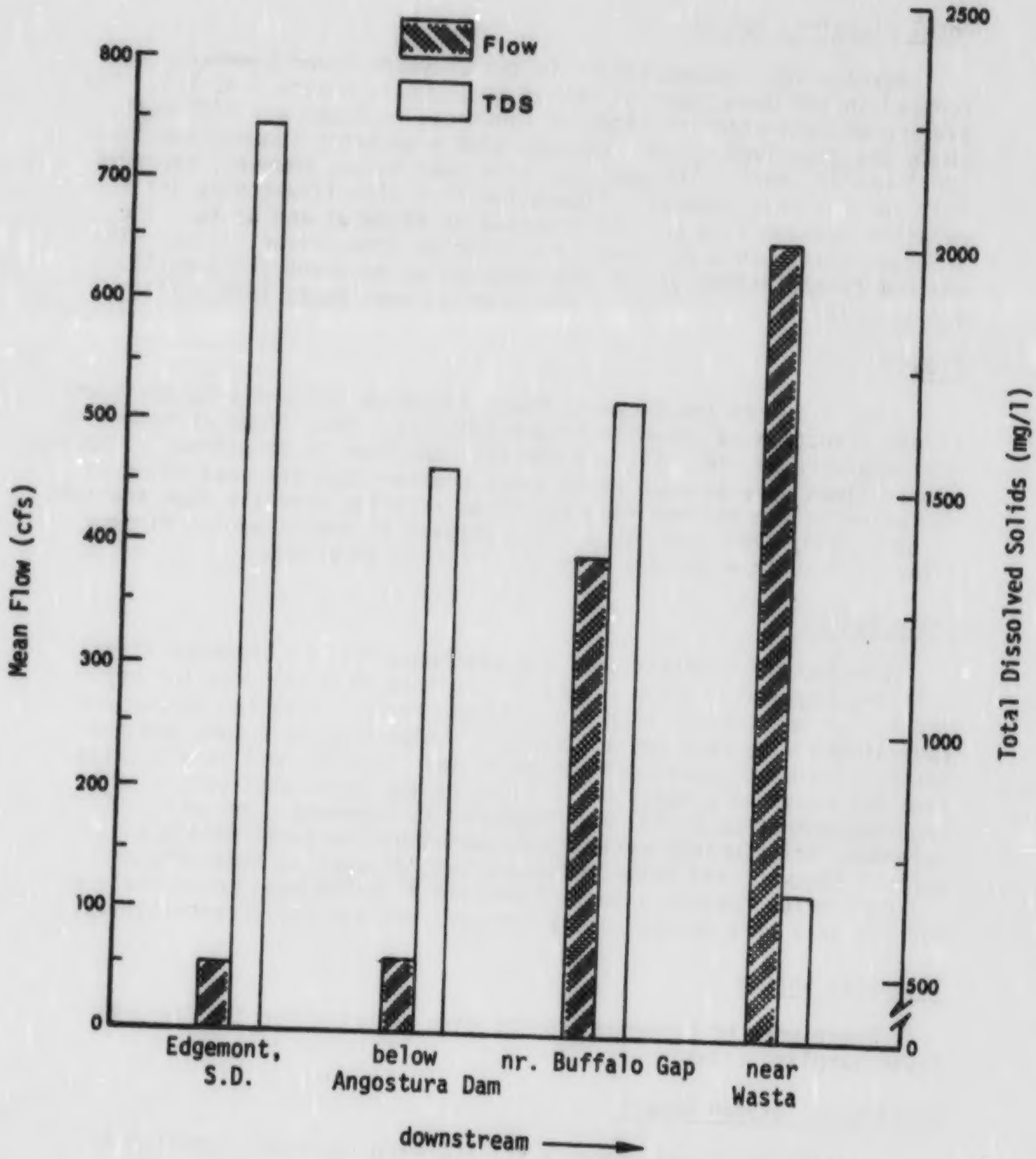

Fig. I-B.11-1 Mean flow and mean total dissolved solids for the period-of-record for selected sampling points on the Cheyenne River.

2.9 and 3.6 mg/l, respectively, while maximum concentrations were 9.4 and 20.0 mg/l, respectively.

Nutrients

Considerable nutrient data exist for the Cheyenne River sampling sites discussed herein. Mean total nitrate concentrations varied from 0.11 mg/l (as N) below Angostura Dam to 0.78 mg/l (as N) near Wasta, with maximum values of 2.0 mg/l (as N) at Edgemont.

Ammonia nitrogen was measured a total of 36 times (Edgemont and Wasta), with a mean concentration of 0.35 mg/l at both stations.

Mean concentrations of total phosphorus as P were reported as 0.5, 0.03, 0.10, and 1.48 mg/l (upstream to downstream). The reported value of 1.48 mg/l T-PO_4 as P is the average of ten measurements made at Wasta, South Dakota during 1969-70. Maximum concentrations of 5.8 and 5.9 mg/l T-PO_4 as P were reported at Edgemont and Wasta, respectively. At no time since 1970 have any total phosphate concentrations greater than 1.1 mg/l T-PO_4 as P been reported.

Temperature

Mean temperatures in the Cheyenne River ranged from 8.6 to 12.7° C, with the maximum temperatures reported as high as 28° C below Angostura Dam.

d. The Fishery

Two streams in the Cheyenne River Drainage support reproducing trout populations and two others provide suitable habitat for planted trout on a small scale. Black bullheads and green sunfish are present in some streams which are unsuitable for trout. The only significant stream fishery is in Stockade-Beaver Creek. The majority of the fishing pressure is on the three major reservoirs on the Cheyenne River, Stockade-Beaver Creek and the numerous farm ponds and stock water reservoirs.

Eleven miles of Stockade-Beaver Creek upstream from Lak Reservoir provide trout habitat. Springs are the water source and flow is generally rapid. Cover and bottom fauna are good. Natural trout reproduction is limited, but improves slightly upstream. Below the Lak Reservoir flows are reduced by irrigation and high summer temperatures,become restrictive for trout.

The major reservoirs on the Cheyenne River do support some fish. Trout exists in these reservoirs and productivity is good. Gamefish populations normally are dependent on planting due to periodic winter kills. Largemouth bass, walleye, pike, brook, brown and rainbow trout have been introduced and survived well between winterkill.

I-B.12 Summary of Present Surface Water Quality

The quality of a body of water can be determined in a variety of ways, and the way chosen is usually related to the use that is to be made of the water. Water quality can be measured by its physical characteristics such as pH, temperature, color, etc.; by its chemical characteristics such as salinity, nutrients, trace elements, etc.; and by its biological characteristics such as the fishery, bacteria, aquatic ecosystem, etc. that it supports.

Present water quality in the Northern Great Plains study area is measured principally at selected point locations. In general most current water quality data are from USGS, EPA, and State water quality sampling stations. These data are largely gross physical and chemical descriptions of water quality. State and Federal Fish and Game Departments have collected biological data as well, though their data are largely confined to fish census data. While there is a definite need for additional baseline water quality data, certain generalizations can be made with the existing data.

The preceding sections gave current water quality profiles for river basins in the NGPRP study area. For the profiles a total of 52 measurement stations were examined. The existing data generally exhibits a high degree of uniformity throughout the area. From the information in these profiles it can be generally concluded that the water quality of the streams in the Northern Great Plains is fair to good. This judgement, however, must be tempered with the realization that sufficient water quality information often is not available to adequately describe the details of water quality.

Much of the water coming into the Fort Union coal region originates at high elevations from snowpack. Warming in May and June produces the melt and provides high rates of runoff. In June, the wettest month, rain can frequently add substantial water to that from melting snow and produce flood conditions. On the other hand, the western Dakota tributaries lie entirely on the high plains and their flows are derived mainly from rainfall. Infrequently they accumulate deep snows and experience early runoff in March or April. Some local tributaries drain soils derived from shales, and quality is locally poor until such flows become mixed with water of better quality which originates outside the Fort Union coal region.

Excellent quality water is generally to be found at the head of streams near the mountain divides. Degradation of the chemical, physical, and biological quality is evident as streams progress downward, resulting from hydrologic, geologic, and man-made influences. Except in a few localized areas, the quality remains satisfactory for irrigation, livestock watering, recreation, fish and wildlife, and municipal and industrial purposes.

Wide variations in the mineral quality of water may be noted in individual streams throughout the program area. In terms of total dissolved solids, high quality water is found in the Yellowstone River. .Average total dissolved solids concentrations from single stations range from 133 mg/l at Dayton, Wyoming on the upper Tongue River to over 2200 mg/l in the upper reaches of the Cheyenne River in South Dakota. The average of all measurements in the Bighorn is 585 mg/l. The Tongue drainage averages a low 380 mg/l. The Powder averages 1425 mg/l, while the Yellowstone averages about 525 mg/l. In North Dakota, the TDS runs about 970 mg/l in the Knife, 855 mg/l in the Heart, 1155 mg/l in the Cannonball and about 440 mg/l in the main stem of the Missouri River. The Belle Fourche River runs about 1540 mg/l and the Cheyenne about 1380 mg/l. Thus, of the major tributaries in terms of flow, the Powder River maintains the poorest quality water of the geographical area as measured by total dissolved solids. Analysis of total dissolved solids data and corresponding flow data show a general correlation between increasing TDS and decreasing flow. This is exhibited in the Bighorn River basin, for example. But simple examination of the preceding flow-TDS figures shows that no simple correlation is possible.

Suspended sediment concentrations and loads vary widely both throughout the region and throughout the year (at a given site). The sediment load is normally light in the upper reaches of the major streams where major precipitation occurs but increases in the middle and lower reaches. Sediment concentrations have historically been detrimental to consumptive uses of water as well as to fisheries and recreation in some stream reaches. The average sediment loads at the mouths of the Yellowstone and Powder Rivers are 0.27 and 0.40 AF/sq. mi./year. More data are needed on suspended solids concentrations since the detailed analysis of individual streams is not available and very few stations are operating. No trends or correlations can be derived.

Biological quality of surface water, characterized by nutrients, dissolved oxygen, and bacterial concentrations is considered good except for some localized problems generally associated with agricultural activities or sewage outfalls. Some areas are in fact considered to be deficient in nutrients to support aquatic life. On the other hand, some areas contain quantities of nutrients at such levels as to indicate the potential for problems from over growth of aquatic plants if further stimulation occurs. The dissolved oxygen level of streams ranges from excellent to satisfactory throughout most of the year with an average of around 10 mg/l for the entire area. The Powder River at Arvada, Wyoming and Moorhead, Montana, with limited measurements, has experienced DO's approaching 5.0 mg/l. Zero DO has been measured at Dickinson, North Dakota on the Heart River (during the winter months). A marked reduction in oxygen levels may be found during the summer below some municipal and industrial wastewater outfalls and in some reaches with low flows resulting from diversions and natural conditions. Bacterial concentrations are generally low due to the low level of population and industrial activity in the Region. The effect on the biological quality of diversions and return flows on stream temperatures is more noticeable in summer months because of the increased use at that time of domestic, irrigation, and industrial water.

Very little data are available describing the concentration of trace elements in the rivers of the Northern Great Plains. Collection of adequate background data is essential. Preliminary data collection of trace elements has not shown serious problems to date.

Lead concentrations from the limited measurements of 40 ug/l or more have been detected at single locations along the Bighorn, Powder, Missouri, and Belle Fourche Rivers. Data suggest the highest concentrations persist along the Missouri. Copper concentrations tend to correlate with high lead concentrations, but the tendency for high concentrations includes the Powder and Belle Fourche Rivers in addition to the Missouri.

Mercury concentrations have been determined in only isolated instances; and with the exception of a number (5) of measurements on the upper Missouri which average 0.4 ug/l, concentrations are at the limit of detection by production methods (0.2 ug/l). Selenium concentrations have, on occasion, exceeded 10 ug/l in the Powder (Morehead), Belle Fourche (state line) and Cheyenne (Edgemont) Rivers. A value of 70 ug/l was recorded for the Belle Fourche Station.

Aluminum concentrations in excess of 200 ug/l have been recorded on the Bighorn (Hardin) and Belle Fourche (Sturgis) Rivers, while the highest average concentrations are shown for the limited data on the Yellowstone River.

Data for boron are comparatively plentiful. Concentrations in excess of 1 mg/l have been recorded for almost every river except the Missouri, Yellowstone, Heart, and Cannonball, where concentrations half that are more common. The Cannonball shows, however, the highest average concentration, about 375 ug/l, while the other rivers range between 110 and 265 ug/l.

The highest zinc concentration measured was 490 ug/l on the Cheyenne at Edgemont. Concentrations in excess of 100 ug/l were also measured on the Belle Fourche (state line). Significantly high concentrations were most persistent in the Cheyenne River, as it is influenced by water quality at Edgemont, South Dakota.

Fluoride data are also relatively plentiful. Concentrations in excess of 1 mg/l have been measured in the Powder River (Kaycee), the Yellowstone (Billings), the Cannonball River (Brein), the Missouri River (Culbertson), the Belle Fourche River (Sturgis), and the Cheyenne River (Angostura Dam and Wasta). One measurement of 8.4 mg/l was recorded at Sturgis, and one measurement of 4.0 mg/l was measured at Kaycee. The locations on the Powder, Belle Fourche, and Cheyenne average over 0.6 mg/1.

For all metals so studied, certain sampling locations seemed to experience high concentrations for more than one metal. For example, Hardin, on the Bighorn, had the highest recorded concentrations of lead, copper, aluminum, and zinc. When data were collected for the Tongue, Miles City was high. Arvada on the Powder River, Billings on the Yellowstone, Williston on the Missouri, and Edgemont on the Cheyenne also possessed this dubious distinction. Along the Belle Fourche, the "honors" fluctuated between the state line (Wyoming-South Dakota) and Sturgis.

Only sparse data are available to describe the radiological quality of streams. Concentrations of radioactivity in the samples that have been taken are below limits generally recognized as safe.

Comprehensive data on the biological activity in the region are scarce. While fishery information is generally available, data for plankton, benthos, and other aquatic organisms are particularly limited. The upper reaches of most of the streams, particularly those in Wyoming and Montana, have good to excellent cold water fisheries. As streams progress downward and onto the plains, fishery quality generally decreases and cold water species are replaced by warm water species.

I-C Important Influences on Water Quality

In this section existing and future water quality influences will be discussed. Subsections discussing water quality problems associated with irrigation, feedlots, power plants, surface mines, and municipalities are presented first. These sections discuss, as appropriate for the category, the water use, water needs, water quality problems, treatment practices, and extent of problems in the Northern Great Plains area. Following these papers is a summary of work under way on trace element water-related problems in the NGP with which the Water Quality Subgroup is familiar. The section ends with a summary discussion of those parameters most likely to be affected by coal development in the NGP.

Possible methods of mitigating the water quality impacts of these otherwise disruptive activities are discussed in Chapter VI.

I-C.1 Agricultural Land Use-Effects on Water Quality

a. Introduction

> "While unable to control the natural climatic forces of flood and drought that affect agricultural operations, the farmer has alleviated their impact through the stabilizing effects of land and water resource development and management. On the one hand, he has recognized the need and has sought flood and erosion control and benefits of better land drainage to rid himself of excess water. On the other hand, he has attempted to combat the effects of drought and seasonal inadequacies in moisture through the careful use and management of the available soil moisture." (The Missouri River Basin Comprehensive Framework Study, Vol. 1, page 119.)

Although the above statement may represent a realistic objective of modern day agriculture, in fact the farmer and rancher face great difficulties in managing the available water resources to such a beneficial degree. The degradation of water quality resulting from various agricultural activities can create significant problems for farmers and ranchers who are unfortunate enough to be located downstream. The Colorado River Basin is the classic example of this problem. Additionally, the biological communities in streams and rivers can be adversely affected by agricultural pollution.

In the Northern Great Plains (NGP) region, two water quality parameters, salinity and suspended sediment, seem to be most adversely affected by farming and ranching activities. In some areas low flows due to irrigation diversions result in high and variable temperatures as well. Salinity (total dissolved solids) is added to natural waters by irrigation return flows due to dissolution and concentration by evaporation and consumptive uses. In agriculture, sediment problems are primarily caused by erosion of pasture and cropland.

The composition and concentrations of suspended particles in surface waters are important because of their effects on light penetration, temperature, solubility products, and aquatic life. The abrasive action of particulate material affects fish and other aquatic organisms. Settleable solids blanket small animals, plants, and their habitats, either killing the organism or rendering the habitats unsuitable for occupation. Suspended particles also serve as transport mechanism for pesticides and other toxic substances which are readily sorbed into or onto clay particles. It is reported[1] that there is no evidence that concentrations of suspended solids less than 25 mg/l have any harmful effects on fisheries. Waters containing concentrations of 25 to 80 mg/l should be capable of supporting good to moderate fisheries, whereas waters with concentrations in excess of 80 mg/l are unlikely to support good fresh water fisheries.

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[1] European Inland Fisheries Advisory Commission. Working Party on Water Quality Criteria for European Freshwater Fish (1965), Report on finely divided solids and inland fisheries. Air Water Pollution, 9:751-168.

The Missouri River Basin, which encompasses the NGP region, currently has only localized salinity and sediment problems. Figures I-C.1-1 and I-C.2-2 show respectively the average salinity and sediment yield for surface waters draining the Missouri River Basin. In the NGP region the Powder River and Western Dakota tributaries have the highest salinity concentrations with averages approaching 1000 mg/l total dissolved solids. Sediment yields vary according to the land's soil type and structure, slope, climate, ground cover, and use. The Powder River historically has higher sediment loads than any river in this region. The principal monitoring station at Arvada, Wyoming shows a mean suspended solids concentration of 23,813 mg/l for the period 1967-1970.

b. Irrigation Return Flow Quality and Control Practices

The concentration of total dissolved solids is affected by two basic processes: 1) salt loading - the addition of mineral salts from various natural and man-made sources, and 2) salt concentration - the loss of "clean" water from the system through consumptive use in plant growth and surface evaporation.

In irrigation the salinity increase due to salt loading is determined by the type of soil, the subsurface geology, and use of fertilizer and other agricultural chemicals. Salt loading occurs until most of the original leachable salts are removed from the soil profile. With reasonable subsurface drainage the salt loading process will take a minimum of 15-25 years for an equilibrium to be reached between the salt content of the soil and that of the applied water.

Changes in salinity levels due to the concentrating of salt may be caused by evaporation from the water and soil surface and by transpiration of water from the root zone by plants. Both of these mechanisms occur for the duration of the irrigation project. The resulting salt load due to the concentrating effect can be estimated using the following equation:

$$L_s = C_s \times q_u \times 2.7$$

where:

L_s = salt concentrated in lbs/acre/year;

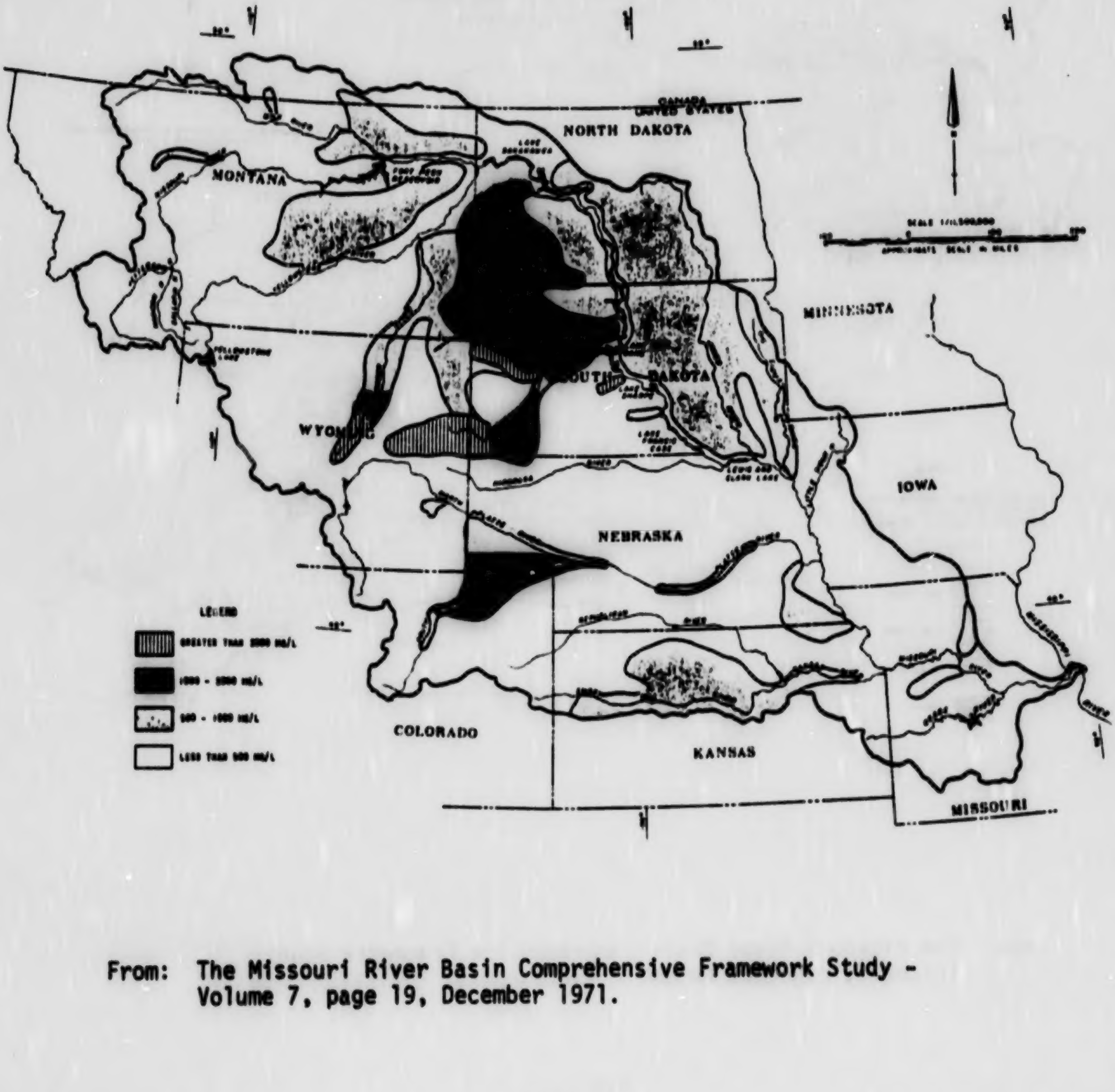
C_s = salt concentration of water applied to the crop in mg/l;

q_u = consumptive use, evapotranspiration, in ft/yr; and

2.7 = dimensional conversion factor.

FIGURE I-C.1-1

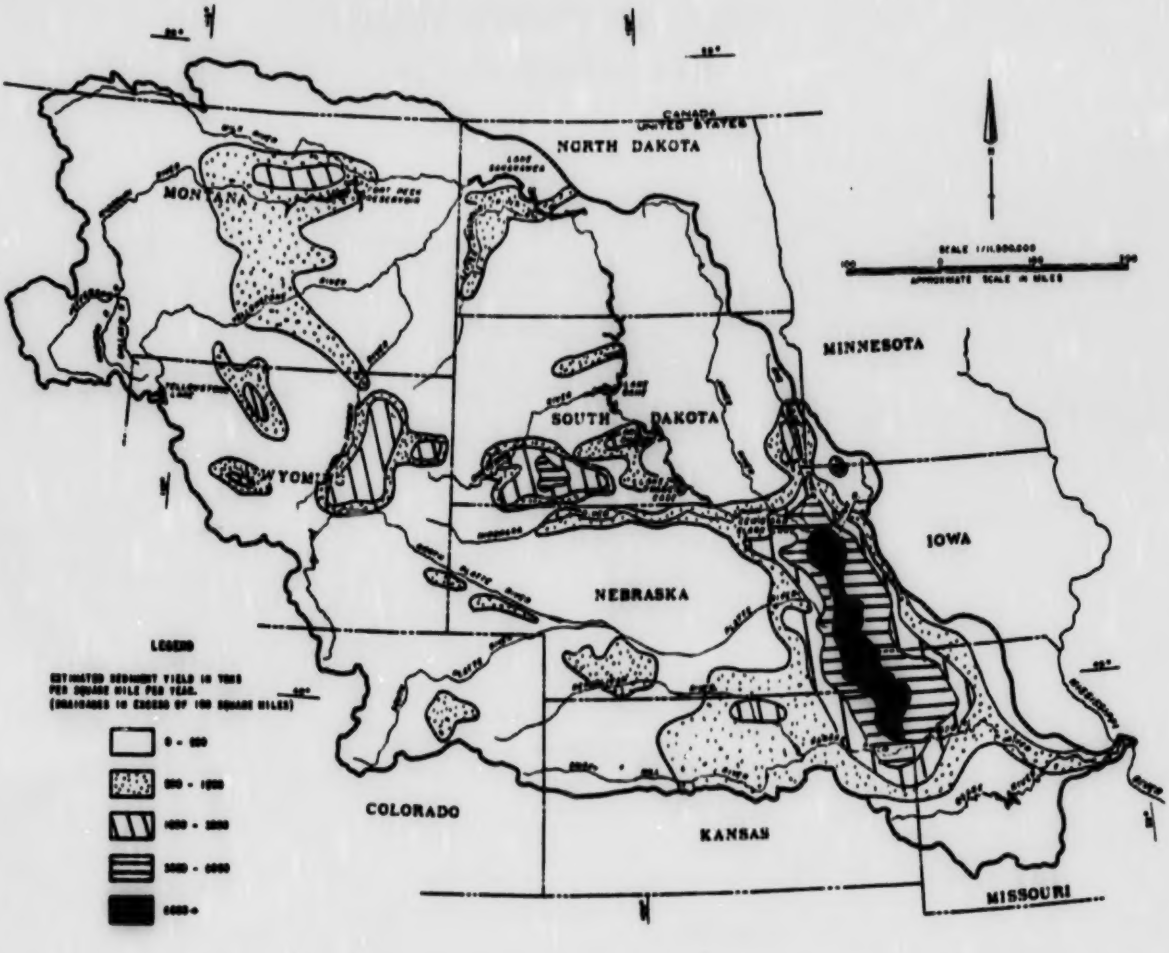
TOTAL DISSOLVED SOLIDS IN SURFACE WATER


CANADA
UNITED STATES
NORTH DAKOTA
MONTANA
MINNESOTA
SOUTH DAKOTA
WYOMING
IOWA
NEBRASKA
COLORADO
KANSAS
MISSOURI
LEGEND
GREATER THAN 2000 MG/L
1000 - 2000 MG/L
500 - 1000 MG/L
LESS THAN 500 MG/L

From: The Missouri River Basin Comprehensive Framework Study - Volume 7, page 19, December 1971.

FIGURE I-C.1-2

SEDIMENT YIELD


CANADA
UNITED STATES
NORTH DAKOTA
MONTANA
MINNESOTA
SOUTH DAKOTA
WYOMING
IOWA
NEBRASKA
COLORADO
KANSAS
MISSOURI
LEGEND
ESTIMATED SEDIMENT YIELD IN TONS PER SQUARE MILE PER YEAR.
(DRAINAGES IN EXCESS OF 100 SQUARE MILES)
APPROXIMATE SCALE IN MILES

From: The Missouri River Basin Comprehensive Framework Study - Volume 7, page 20, December 1971.

Some estimates indicate that as much as sixty percent of the total water applied as irrigation water is lost to evapotranspiration. Water lost by this process is essentially salt free, thus the net effect on salt concentration could be a 2½-fold increase in the return flow if only this mechanism is active.

Irrigation return water can be subdivided into two general categories based on potential degradation levels, 1) surface return flows and 2) water percolation through the plant root zone. A typical irrigation return flow system is presented in Figure I-C.1-3.

Surface return flows contribute relatively little to the concentration of salts. Such water will retain approximately the same levels and composition of minerals as the water diverted for irrigation, if relatively short application times are used. However, if the irrigation water is not properly managed, the receiving stream may experience effects from surface return flows such as, 1) an increase in sediment load, 2) an increase in pesticide and herbicide concentration, 3) a slight increase in the concentration of salts, and 4) an increase in bacteria concentrations from certain fertilizers and livestock. With correct management practices, these contributions can be reduced. Surface return flows can be eliminated by regulating amounts and rates of application, or this water can be reused by pumping back to the point of initial application or used to irrigate fields adjacent to the original site. One hypothesis of correct water management is that the necessary amount of water applied is only that required to maintain a favorable salt balance in addition to providing the consumptive use requirement of the crop. A favorable salt balance is maintained if all the salt concentrated by evapotranspiration is leached from the root zone. Over-application of water will result in greater leaching of salts which is not necessary for good crop production.

c. Sediment Production from Crop and Pasture Land

Water erosion, the major source of sediment, is a complex process. Climate, topography, and type of soil are important factors and generally are uncontrollable. On the other hand, land use, conservation tillage, and other conservation measures are subject to management and control.

The form, volume, intensity, and distribution of precipitation are important determinants of erosion. Erosion of sloping land increases as volume and intensity of rainfall or runoff from snowmelt increase. Perhaps even more important is the distribution of precipitation throughout the year. Rainfall occurring during periods when ground cover is inadequate is more damaging than a similar rainfall when the ground is protected.

Length and gradient of slopes affect erosion. The erosion hazard increases as slopes become longer and steeper. Slope shape determines

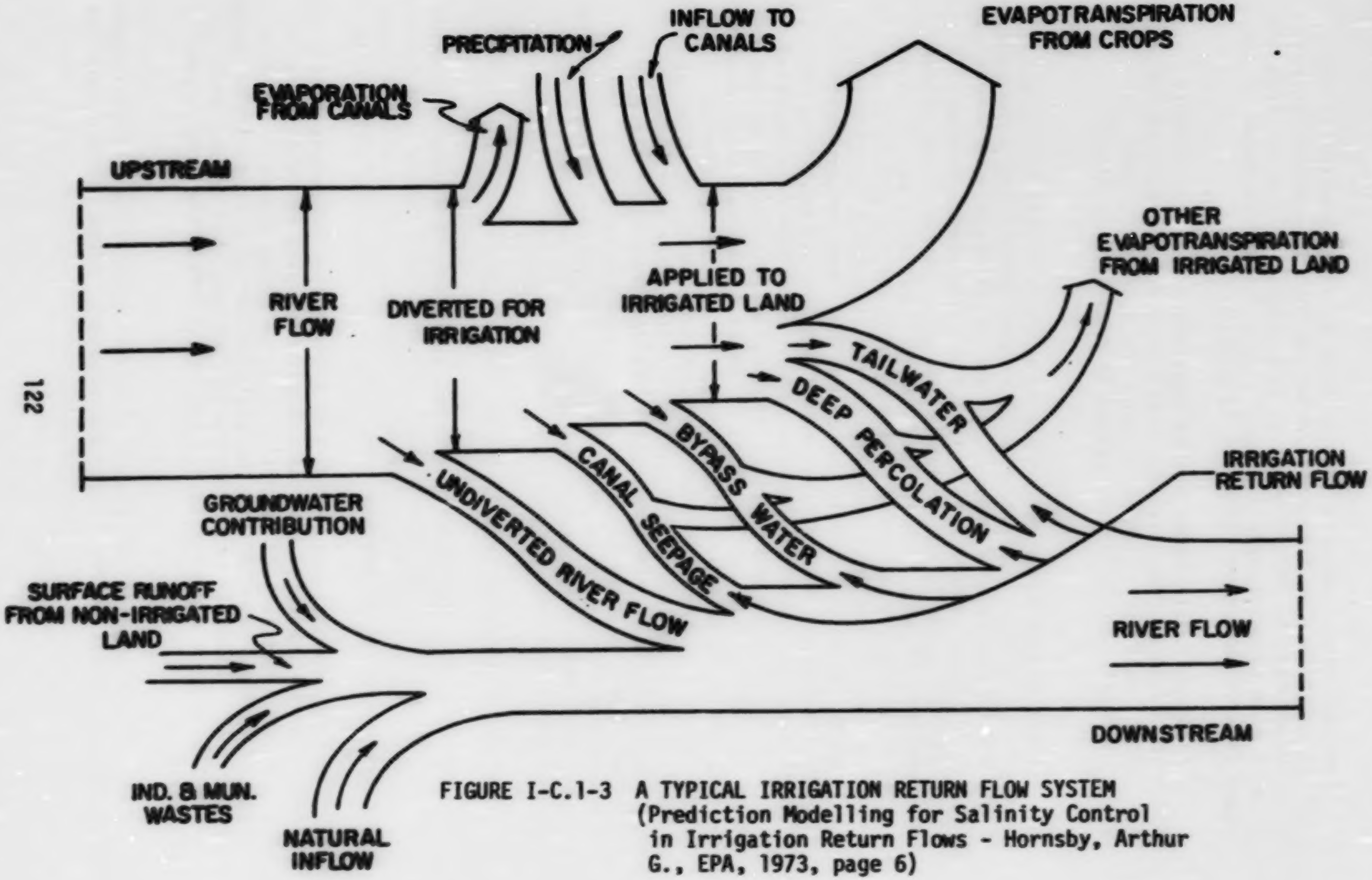

EVAPORATION FROM CANALS
PRECIPITATION
INFLOW TO CANALS
EVAPOTRANSPIRATION FROM CROPS
UPSTREAM
RIVER FLOW
DIVERTED FOR IRRIGATION
APPLIED TO IRRIGATED LAND
OTHER EVAPOTRANSPIRATION FROM IRRIGATED LAND
TAILWATER
DEEP PERCOLATION
BYPASS WATER
CANAL SEEPAGE
UNDIVERTED RIVER FLOW
IRRIGATION RETURN FLOW
GROUNDWATER CONTRIBUTION
SURFACE RUNOFF FROM NON-IRRIGATED LAND
RIVER FLOW
DOWNSTREAM
IND. & MUN. WASTES
NATURAL INFLOW

FIGURE I-C.1-3 A TYPICAL IRRIGATION RETURN FLOW SYSTEM (Prediction Modelling for Salinity Control in Irrigation Return Flows - Hornsby, Arthur G., EPA, 1973, page 6)

whether soil will move off the field or be deposited on the field at a point farther down the slope. Complex topography makes installation of erosion control practices difficult.

Soils vary in their susceptibility to erosion. Many factors are involved in determining the erodibility of a particular soil. The most important of these are particle-size distribution (texture), organic matter content, soil structure, and soil permeability.

The canopy protection of crops and pasture depends not only on the types of vegetation and the quality of growth, but it also varies over the months and seasons. Therefore, the overall erosion-reducing effectiveness of a crop or grass depends directly on how much protection is provided during the summer months of the year when most of the erosive rainstorms occur.

The interaction of the factors discussed above has been studied in many locations for several decades. The effects on soil losses of combinations of these factors and various erosion control practices can be predicted utilizing the Universal Soil Loss Equation developed by Wischmeier and Smith[1] (See also Appendix II).

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1. Predicting Rainfall-Erosion Losses From Cropland East of the Rocky Mountains, 1965, U.S. Department of Agriculture, Agricultural Handbook No. 282.

I-C.2 Water Pollution Potential Due To Feedlots In The Northern Great Plains

a. Introduction

Animal confinement facilities, commonly known as feedlots, have become the primary source of meat and the animal products in the United States since World War II. Feedlots are more prevalent in the Great Plains where an abundant supply of feed can be produced close at hand. In the Northern Great Plains where crop production is more restrictive, the numbers and capacities of feedlots are smaller, farm feeder operations predominate over custom feeding facilities.

A farm feeder usually owns the livestock and normally feeds fewer than 1000 cattle or the equivalent capacity in other livestock, such as sheep or hogs, as part of a general farming operation. These feeding operations developed as a way of supplementing the general farm income and thus, were located at pre-existing farm building sites commonly adjacent to receiving waters. Only in recent years has the location of feedlots near streams attracted major concern in terms of their water pollution potential.

For the purposes of this discussion a feedlot shall mean a concentrated, confined animal growing or holding operation where crop or forage growth or production is not sustained in the area of confinement. All feed is transported to and not grown at the lot. The complexity of the feedlots may range from simple open unsurfaced pens utilizing manual feeding to automated enclosed facilities with slotted concrete floors and integrated feed and waste control systems. Those facilities common to the Northern Great Plains are open unsurfaced lots and the primary source of animal wastes is from beef cattle production. This discussion is thus directed to these smaller cattle feedlots.

b. Waste Sources

The major source of water pollution results from the organic material contained in runoff out of the confinement area, from liquid and solid waste disposal areas, and from manure and other materials storage sites associated with the feedlot. Manure and runoff that accumulate at the lot may produce a malodorous situation as bacterial decomposition takes place. These wet pungent conditions which are most prevalent in the NGP during summer rainy season produce an attractive breeding ground for insects, thus creating a potential health hazard where manure is so stored.

c. Waste Production

Feeder cattle start in the feedlots at a weight ranging from 650 tc 750 pounds and are fed to a finished market weight of 1000 to 1200 pounds within 140 to 160 days. The typical steer or heifer in confinement weighs about 800 pounds, eats about 20 to 30 pounds daily at a conversion rate of 7 to 9 pounds feed per pound of animal gain, and produces about 50 to 60 pounds wet weight of waste (urine, feces, and bedding). This waste combination, or manure, has an estimated five-day BOD potential of 1 to 2 pounds per head daily, or as much as ten people produce daily. However, such a BOD_5 loading could only be exerted if all manure were slurried immediately after excretion and the total then discharged directly to a receiving stream. This will not normally happen even on a feedlot having no runoff controls and located adjacent to a stream.

In the smaller farm feeder operations the manure is mounded in the pens and then removed about 2 or 3 times per year. Principal use is in the Spring and Fall. During the period of storage in the pens, the manure undergoes a large degree of decomposition to a more stabilized less oxygen-demanding state. When precipitation does occur, the manure pack on the pen floor absorbs a portion of the rainfall dependent upon various factors (e.g. slope, animal density, cover, rainfall intensity and duration, pen surface condition). The rainfall not absorbed drains from the feedlot as runoff. It is this runoff that produces a direct water quality problem on an adjacent receiving stream. Many of the feedlot operations in the NGP, as farm associated activities, were sited along streams to provide stock watering, good drainage, and a natural waste disposal system. Thus, a high potential exists for water quality degradation.

With no means of runoff control the drainage from a feedlot can produce a slug effect, particularly in the NGP, where the heaviest rainfall is most commonly the result of high intensity, short duration thunder storms occurring during the summer months. This slug runoff is characterized with high organics, nitrogen (mostly ammonia), and bacterial counts. The wide range, but generally poor quality of feedlot runoff, is illustrated in the following table:

TABLE I-C.2-1

Ranges of Runoff Quality from Unpaved Feedlots

Parameter Units	Quality Range
pH, units	6.6 - 9.4
BOD_5, mg/l	2,000 - 20,000
COD, mg/l	1,300 - 77,000
Conductivity, millimhos	1.0 - 11.5
Total solids, mg/l (%)	2,000 - 200,000 (0.2 - 20)
Total suspended solids, mg/l (%)	1,000 - 200,000 (0.1 - 20)

Parameter Units	Quality Range
Volatile solids, mg/l (%)	1,000 - 10,000 (0.1 - 10)
Ammonia Nitrogen (N), mg/l	20 - 2,000
Nitrate Nitrogen (N), mg/l	0 - 80
Total Nitrogen (N), mg/l	60 - 5,800
Total Phosphorus (P), mg/l	7 - 800

Winter runoff (snowmelt) can be more concentrated than rainfall runoff because of much lower dilution. The quality range given includes both winter and rainfall conditions. Data on bacterial counts are too variable to typify.

d. Impact on Water Quality

Although wastes from feedlots may have had a significant impact on water quality in the NGP in the past, this is rapidly being negated through the implementation of federal and state effluent standards. Such standards basically allow no discharge from feedlot facilities except for the excess of runoff from a rainfall more severe than a 10-year - 24-hour storm[1] or, for new facilities, a 25-year - 24-hour storm[1]. At those times when any discharge would be permitted, the effluent would be clarified (suspended material removed) before discharge, and the receiving stream would be at a high stage. Thus the impact on water quality is reduced to a level where it may not be measurable.

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[1] That maximum amount of precipitation that has been recorded as falling in a 24-hour period at least once every 10 or 25 years.

I-C.3 Projected Effluents from Power Plants in the NGP Area

Steam electric power plants are the production facilities of the electric power industry. Figure I-C.3-1 is a simplified schematic of the process. In the past, steam electric generating units were normally small, 100-200 MW, and located near the load center. Today, most new fossil fired generating units are 500-1000 MW in size and frequently are located at a coal mine to minimize fuel transportation costs. The generated electricity is then transmitted to the load centers via high voltage electrical transmission lines.

Water is used in a steam electric plant for a variety of uses. A more detailed analysis of water needed in power plants is contained in Chapter II. The thermodynamic process employed to generate electricity has inherent limitations. For a typical new plant almost 9000 BTU of heat must be provided to generate one kilowatt-hour of electricity. Direct (non-loss) conversion would require only 3413 BTU/kw-hr. But conversion is not particularly efficient. The remainder of the heat is not useful and must be removed. In the past this has been accomplished with cooling water either recirculated or passed once through the heat exchangers. Water is also used in the boiler. Boiler water must be extremely pure and is therefore treated extensively prior to use. Ash generated when coal is burned is generally sluiced with water to a pond for disposal. Water is also used to clean equipment; for domestic uses at a plant; and in air pollution control devices such as scrubbers. A 1000 MW unit, fired with coal, can use anywhere from about 500 acre feet of water to 0.5×10^6 acre feet of water per year depending on the type of cooling employed at the plant[1].

The main use for water at steam electric generating stations remains cooling. The theoretical thermal efficiency of a power plant is limited by the ideal carnot efficiency which is $uc = 1 - \frac{\text{cooling water temp.}}{\text{turbine steam temp.}}$ The peak carnot efficiency is about 70% for today's equipment. The actual cycle used at power plants more closely approximates the less perfect Rankine cycle. Because of additional losses in a plant (thermal, mechanical, etc.) the actual efficiency of a new plant is only about 40%. The efficiency is given by the following formula:

$$u = \frac{3413 \text{ BTU/kw. hr}}{3413 \text{ BTU/kw. hr.} + \text{waste heat (BTU/kw. hr.)}}$$

The denominator of this equation is known as the "heat rate" of a plant and is a common measure of performance. The heat rate of the best plant in the U.S. has dropped from 15000 BTU/kw-hr. in 1925 to 8588 BTU/kw-hr. in 1962 (an efficiency of about 40%).

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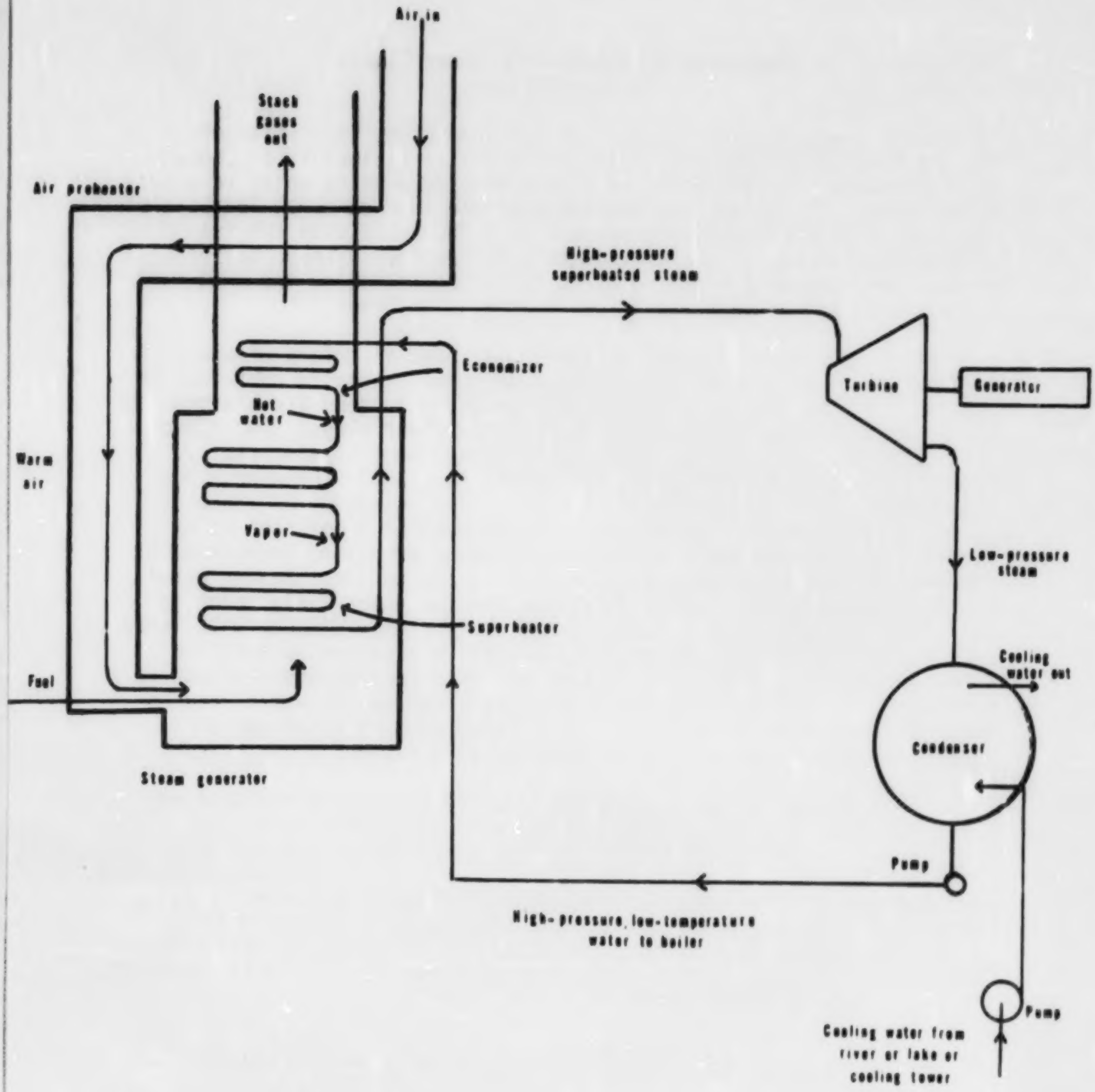
[1] The low value assumes dry cooling and no wet scrubbing for SO_2 removal. The high value is for once-through cooling.


Air in
Stack gases out
Air preheater
High-pressure superheated steam
Economizer
Hot water
Turbine
Generator
Warm air
Vapor
Low-pressure steam
Superheater
Cooling water out
Fuel
Condenser
Steam generator
Pump
High-pressure, low-temperature water to boiler
Pump
Cooling water from river or lake or cooling tower

Fundamentals of Classical Thermodynamics
VanWylen, Gordon J. and Sonntag, Richard E.,
John Wiley and Sons, Inc., 1965, Page 2

Figure I-C.3-1 Simplified schematic of steam electric cycle.

For a typical 1000 MW coal fired unit in the Northern Great Plains, utilizing a wet mechanical draft cooling tower, the heat rate can be expected to be around 9000 BTU/kw. hr. -- an efficiency (u) of 38%. Table I-C.3-1 shows representative calculations for the amount of cooling water needed for such a plant. The evaporation loss at full load would average 15.6 cfs. If drift were held to .005% of the circulating water flow (total throughput estimated to be almost 700 cfs if a 17° C temperature rise is experienced in the condenser) and five cycles of concentration could be achieved, the blowdown rate would be 3.9 cfs. The water requirement for such a plant, for cooling purposes only would be about 19.5 cfs or almost 20 cfs (at full load under design conditions for one year actual water needs would be less). By comparison, water would be needed only for boiler makeup, from 1 to 2 cfs, if a dry cooling tower were used, but would be needed at a rate of 700 cfs (or greater depending on condenser ΔT) if once-through cooling were used. If wet scrubbers are used for air pollution control, then another 3 to 5 cfs are required.

Water is the circulating fluid in the boiler-turbine condenser cycle. In today's high pressure (3500 psi), high temperature (538° C) boilers extremely high water purity is required. Therefore, all power plants must have a water treatment plant. Water to be treated (boiler water plus sanitary water, etc.) is usually treated first with a clarification process. This is frequently combined with a lime softening process. Boiler water is then further treated by either evaporation or ion exchange. Both true ion exchange, where a sodium zeolite softener is used, and demineralizers, where hydrogen is substituted for dissolved ions, are used. All of these treatment processes produce waste, generally which is high in total dissolved solids. Makeup water for the boiler is required because of a small percentage of the boiler water must be continually removed to control the buildup of total dissolved solids in the boiler.

A third use of water in a power plant is for ash sluicing. Most coals consist of 5-15% ash. Some of this ash must be removed from the boiler as bottom ash and some must be removed from the stack gases as fly ash. Frequently bottom ash is sluiced from the boiler to ponds where the ash settles out and the water is discharged. Although fly ash is generally collected dry, it may also be sluiced to a disposal site. It is possible to recycle water used for bottom ash sluicing to reduce the water requirement.

Water is also used for a variety of miscellaneous uses in a power plant. Water is used in maintenance, such as annual boiler cleaning or cooling tower basin cleaning. It is also used for a variety of domestic uses; drinking water, showers, restrooms, floor cleaning, etc. In addition, new air pollution control devices, designed for both particulate and sulfur dioxide removal, scrubbers, can be a significant water user.

TABLE I-C.3-1

Cooling Water for a Typical 1000 MW Plant

1. Coal fired

   9000 BTU/kw-hr (heat rate)
   38% efficiency (4)

   10% inplant heat losses (conservative)

2. Heat rejected to condenser water

   9000 BTU/kw-hr - 10% = 8100 BTU/kw-hr
   8100 - 3413 (to elec.) = 4687 BTU/kw-hr

   4687 BTU/kw-hr = 4.69×10^9 BTU/hr for 1000 MW unit

3. Assume: 1000 BTU/lb_m for steam condensing (lb_m = pounds mass)
   75% of heat transferred by evaporation

4. Evaporation loss

$$\frac{(4.69 \times 10^9 \text{ BTU}) \; (.75) \; bl_m = 3.52 \times 10^6 \; (lb_m/hr)}{hr \; 1000 \text{ BTU}}$$

   15.6 cfs - average for full load

5. Circulating water flow: assume 30°F ΔT

$$4.69 \times 10^9 \text{ BTU/hr} = m \left(1 \frac{\text{BTU}}{{}^\circ lb_m}\right)^{*} 30^\circ \text{ F}$$

   * (specific heat of water)

   $m = 1.56 \times 10^8 \; lb_m/hr$
   or 694 cfs

6. Drift assume equal to .005% of circulating flow
   5×10^5 (694) = .035 cfs

7. Calculate blowdown

$$B = \frac{\text{Evap. - Drift (cycles of conc. - 1)}}{\text{Cycles of conc.}}$$

   Evap. = 15.6 cfs
   Drift = .035 cfs

Table I-C.3-1 (continued)

Inlet TDS (mg/l)	Cycles of Conc.	Outlet TDS/mg/l	Blowdown (cfs)
2500	2	5000	15.6
1000	5	5000	3.9
500	10	5000	1.7
250	20	5000	.8

8. Other evaporation rates

average annual (85% capacity factor)
13.3 cfs

maximum (95% of heat lost by evaporation)
19.8 cfs

9. Other significant wastes

Boiler blowdown (1 to 2 cfs) (could be makeup to cooling tower)

Ash sluicing (cooling tower blowdown furnishes makeup water needed for recirculating) ash system; no additional water required

Water treatment effluent (4 gal per day per capita; 200 employees; = 0.01 cfs)

Area (coal pile) surface drainage (can be captured & treated)

Scrubber for flue gas removal (3 to 5 cfs)

However, many uses of water in a power plant can utilize water discharged from another part of the plant, thereby minimizing "new" water requirements and minimizing the need for a water discharge. Boiler blowdown is of suitable quality to use for cooling tower makeup. Cooling tower blowdown is a good source of makeup for an ash sluicing system. All potential effluents; ash sluice water, treated domestic wastes, cooling tower blowdown, etc., are satisfactory makeup for an air pollution control scrubber. With the use of either good water or water treatment; the preceding analysis shows the amount of water to be disposed to be small (ca 4 cfs or less), the potential for disposing of most waters by evaporation is high.

There is no regulation at this time that would require all new power plants to contain all liquid wastes. Plants in operation today generally do not recycle ash sluice water. Some newer plants do use cooling tower blowdown as makeup water to the ash sluice system, but not all. Because the coal regions of the NGP are in a semi-arid area, we can expect most new plants generally to have cooling towers, with the cooling tower blowdown to be used as ash sluice water. Without regulation, it remains possible that ash sluice water, after settling in a pond, will be discharged. If that is the case, a 1000 MW power plant would probably have an effluent on the order of 1.5 to 3 cfs. The total dissolved solids in the effluent would probably be around 5000 mg/l with less than 30 mg/l of suspended solids. The pH would most likely be in the 7-8.5 range. Evaporation of 1.5 cfs could require in excess of 300 acres in the NGP.

Because the NGP area is so water short, it is possible that dry cooling towers, instead of wet cooling towers, may become common. Although a small blowdown (and makeup) remains, it would not be sufficient to supply an ash sluice system unless extensive recycle were employed in the ash system. Nor would the blowdown support a wet scrubber system, and an additional 3000 AF/yr would be required. Plants utilizing dry cooling towers would probably not have a liquid discharge.

If scrubbers become the predominant air pollution control device in the NGP, liquid effluents could be decreased. Overall plant water requirements, if wet cooling was used with recycle to a scrubber, would not increase. However, if dry cooling was used, plant water requirements would increase for the scrubber. SO_2 scrubbers utilizing current technology create significant amounts of sludge. Water which constitutes blowdown from the system is tied up in the sludge. Therefore, a reduced liquid effluent (or no liquid effluent) is achieved.

Overall plant water requirements for a 1000 MW plant are currently estimated by other NGPRP work groups as 15,000 acre feet per year for wet tower cooling with sufficient leeway for a wet scrubber. The water work group initially estimated 19,000 acre feet for a 1000 MW plant, and though that is now recognized as too high, it was used in the regional calculations.

Some incomplete data for two small coal-fired power plants are presented in Table I-C.3-2. Increases in TDS are shown and are expected. The pH increase in the ash pond overflow is also reasonable.

In summary, two somewhat opposing points seem important. First, it appears important that any new power plant built in the NGP area have a minimum water requirement. Recycle, reuse and conservation should be practiced. Tools for requiring this are developed for plants that have discharges via the NPDES permit program. Second, because it is possible with present regulations for new plants to have discharges, it remains important that analyses of water quality effects of coal development project some plants as having a discharge.

TABLE I-C.3-2

Water Quality Data from Power Generating Stations

Station A (Wyoming)	Parameter (mg/l or as noted)	Date	Concentration Inlet / Outlet
	Total Suspended Solids	7 Jul 71	6. / 5.
	Chemical Oxygen Demand	7 Jul 71	52. / 8.
	Total Dissolved Solids	7 Jul 71	100. / 890.
	Total Volatile Solids	7 Jul 71	100. / 220.
	Phosphorus (as P)	7 Jul 71	0.02 / 0.85
	Ammonia (as N)	7 Jul 71	<0.1 / <0.1
	Nitrate (as N)	7 Jul 71	0.1 / 0.1
	Chloride	27 Aug 71	- / 9.
	Chromium	27 Aug 71	- / 30.
	Phenol	27 Aug 71	- / 3.
	Zinc	27 Aug 71	- / 40.
	Sulfite	27 Aug 71	- / <1.0

Station B (North Dakota)	Date	Total Solids River/Ash Pond* (mg/l)	Suspended Solids River/Ash Pond* (mg/l)	pH River/Ash Pond* (mg/l)	Temperature River/Ash Pond* (°F) **
	1 Jun 72	222 / 686	3 / 5	7.8 / 10.7	71 / 83-77
	9 Jun 72	410 / 632	3 / 9.5	8.3 / 10.7	66 / 86-78
	16 Jun 72	432 / 624	40 / 77	8.1 / 9.8	68 / 88-81
	23 Jun 72	566 / 1529	154 / 642	8.2 / 9.3	64 / 88-82
	30 Jun 72	394 / 572	8 / 7	8.2 / 9.0	69 / 89-82
	6 Jul 72	428 / 585	6.0 / 5.5	8.3 / 8.7	69 / 86-81
	12 Jul 72	415 / 662	5.5 / 3	8.7 / 8.7	66 / 88-80
	20 Jul 72	428 / 776	8 / 6	8 / 9.1	62 / 91-85
	26 Jul 72	434 / 1010	7.5 / 5.5	7.5 / 10.3	66 / 89-86
	3 Aug 72	424 / 893	4.5 / 5	8.3 / 9.8	64 / 90-85
	16 Aug 72	407 / 693	6.0 / 4.5	8.2 / 8.8	69 / 91-87

Note: All data were obtained from discharge permit applications and must be considered preliminary.

* Discharge   ** Maximum - Minimum

I-C.4 Water Quality Impact from Coal Mining in the Northern Great Plains Area

a. Introduction

A significant amount of the coal in the Northern Great Plains area can be mined by surface mining techniques. Surface disturbances of 25-75 acres per million tons of coal[1] have been projected for the West. When considering the three NGP Coal Development Profiles which forecast 144, 362, and 977 million tons of coal mined per year in the NGP by the year 2000, it is obvious that hundreds of acres would be disturbed. However, the surface areas remain a small portion of the total area. The following discussion is a preliminary analysis of possible effects, methods for prediction of impacts, and measures that can be taken to minimize adverse impacts on water quality as increased mining occurs.

b. Water Quality Impacts

General Discussion

Existing surface water quality conditions in the Northern Great Plains have been summarized in Chapter I. Streamflows in most of the small streams likely to be impacted vary tremendously, primarily because the flow is controlled by seasonal distribution of precipitation. Annual precipitation in the area of strippable coal in the Northern Great Plains ranges from 12-16 inches, annual snowfall ranges from 30-70 inches,[2] and annual evaporation rates are as high as 50 to 60 inches (Class A Pan)[3], though lake evaporation is closer to 30 inches. Runoff in many areas is less than one inch due to infiltration, evaporation, and other losses.

Ground water quantities and quality are also quite variable throughout the NGP. Many of the near-surface coals are portions of the shallow aquifers.

The major parameters of economic and environmental significance that may be affected by surface coal mining activities are shown below in Table I-C.4-1.

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1. "Rehabilitation Potential of Western Coal Lands" National Academy of Sciences.
2. Selected Climatic Maps of United States - Environmental Data Services, Environmental Science Services Administration, 1966.
3. Bureau of Mines Information Circular 8328, Water Requirements and Uses in Wyoming Mineral Industries, Gilkey & Stotelmeyer, 1967.

TABLE I-C.4-1

Water Quality Parameters Affected by Coal Mining

Total Dissolved Solids

Sulfate

Sodium and Potassium

Sodium Percentage (of cations)

Total Suspended Solids

Total and Dissolved Iron

Hardness

Acidity - Alkalinity - pH

Other parameters that are of interest, but need to be examined only on a case by case basis are listed in Table I-C.4-2.

TABLE I-C.4-2

Secondary Water Quality Parameters Affected by Coal Mining

Total Lead

Total and Dissolved Aluminum

Boron

Dissolved Molybdenum

Total Cadmium

Nitrates

Total Zinc

Total Mercury

Sulfide

Total Copper

Total Selenium

(Other trace elements found in coal or in disturbed overburden in concentrations exceeding 1 ppm).

Due to the nature of most coal (and lignite) in the Northern Great Plains area, knowledge of the water quality problems associated with coal mining in the eastern part of the United States cannot be used in an analysis of water quality problems associated with coal mining in the Northern Great Plains. Coals in the Northern Great Plains area usually contain no more than 1.0% sulfur and therefore commonly do not result in acid formation when contacted by air and water. This single factor is the most important difference between eastern coals and western coals. Other important factors of major significance include the arid climate and the relationship between surface disturbance, coal production and coal thickness.

Surface Disturbance

The surface disturbance due to strip mining includes not only the area of overburden removal and deposition and the active pit, but also loading facilities, crushing and screening facilities, access and haul roads, water control structures and impoundments, stream diversions, equipment maintenance and building areas, exploration activities, and sanitary waste facilities. All of these surface disturbances represent potential runoff problems. Suspended solids from erosion of disturbed areas is the most obvious potential pollutant. However, dissolved solids can also be important.

Pit Dewatering

In many cases ground water is intercepted either from the coal seam or, to a lesser extent, from the strata of the overburden, resulting in a net inflow and accumulation of water in the active pit. Perhaps the greatest potential for water pollution in a surface mine occurs when this water is discharged. Though the coal itself may be of low sulfur content, low grade or refuse coal immediately adjacent to the coal seam may contain sulfate minerals and may thus provide a source, when disturbed, of otherwise uncommon elements that may be leached from the materials. In addition, the water may come into contact with oil and grease. The ground water will typically be of fair quality as it issues from the undisturbed coal. If the ground water is instead derived from shales, it may be expected to contain a high percentage of sodium and high concentrations of sulfate and total dissolved solids.

Sanitary Facilities

Changerooms, shower rooms, food service facilities and company towns may all be associated with mining sites. These facilities require waste treatment facilities. Generally such wastes are handled via septic tank facilities and/or lagoons. These wastes are discussed in Section I-C.5.

Equipment Maintenance

Potential pollution from equipment maintenance may occur in areas of fueling, oiling and lubrication, washing of shop floors, and wherever the equipment is utilized. Possible pollutants include oils, greases, fuels, anti-freeze, suspended solids, detergents, and others.

Fugitive Dust

Atmospheric fallout and washout of fugitive dust may contribute pollutants to surface waters. Potential sources of windblown material include hard roads, coal crushing, screening and loading, and wind erosion of unreclaimed areas. Significant pollutants are suspended and dissolved solids.

Equipment Emission Fallout

Equipment operating in the mining area that employ diesel or gasoline engines will emit a variety of atmospheric pollutants that may fall out onto the surface property and ultimately be dissolved or suspended in the runoff.

Where leaded fuels are employed it has been demonstrated that elevated lead levels are found in the soil and plants along highway right-of-ways[1]. Mostmine vehicles will not commonly be fueled by leaded fuels; most are diesel or diesel-electric units. Other parameters from equipment emissions may include other fuel additives or components, and unburned hydrocarbons.

Coal Processing

As a general rule, no coal washing is performed in the NGPRP area. The only processing normally performed is crushing and screening prior to loading. If performed in the open, these operations could be sources of fugitive coal dust, but weather conditions usually dictate that such facilities be housed and dust problems are then associated more with loading than crushing.

Generally, the coals in the NGPRP area are not washed due to their substantial thickness and thus the resulting ability to remove them under reasonably clean conditions and the lack of inorganic sulfur.

Where removal of ash-forming or inert materials becomes important and those coals are not transported great distances, washing of coal is not practiced. However, as distances of transport increase, or as customers demand higher BTU, lower ash material, washing may be required. Since most NGP coals have lower BTU values of around 8,000 to 9,000 BTU per pound, they will not be utilized in industries requiring coal with a quality high heating value.

If coal washing were to become more common in the NGP, a "no discharge" (evaporation) system might be attempted. Any water quality impact would then be related to consumptive use of water; losses caused by evaporation and sorption by the coal. However, wastage of coal fines would have to be addressed.

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[1] "Environmental Lead Distribution in Relation to Automobile and Mine and Smelter Sources" Gary L. Rolfe and J. Charles Jennett. International Conference on Heavy Metals in the Aquatic Environment, Vanderbilt University, Nashville, Tenn., Dec., 1973. Up to 425 ppm and 45-50 ppm by weight respectively on high volume roads have been measured. The location of concentrated or elevated lead levels may reasonably be expected to occur downwind of the prevailing winds, and usually within a few hundred meters of the road.

Blasting

Blasting of overburden and breaking of coal is commonly utilized ahead of both overburden removal and coal loading. Residuals of the blasting agents are potential pollutants of runoff or ground waters that may dissolve them. Possible pollutants include nitrogen compounds, particularly ammonia and nitrites, and fuel oil. In one case mercury was believed to have come from the use of blasting agents containing mercury. No direct correlation between blasting and pollutants has been achieved for surface coal mines.

Modification of Stream Channels

Not infrequently, the stripping operation will progress through a natural stream channel. Improper planning or execution of the mining can obviously result in extreme erosion and the resultant increases in total suspended and dissolved solids downstream. Relocation of a stream too close to the active pit and without sufficient protection between the stream channel bottom and the coal can result in excessive infiltration of surface water into the pit. Channelization of streams can result in either enhanced erosion or sedimentation if gradients are not maintained. Channelization also disrupts the aquatic habitat.

Modification of Stream Flows

Through changes in the runoff characteristics of the mined or mining area, local stream flows may be changed. Total impoundment, irrigation of reclamation areas or enhanced infiltration may result in locally lowered surface flows due to the infiltration, evaporation from depressions and evapotranspiration. On the opposite extreme, runoff may be increased due to lack of vegetation on unreclaimed areas or significantly increased clay content of the surface materials resulting in decreased infiltration. This may result in surge type flows and loss of the perpetual nature of a stream if it is also accompanied by loss of ground water discharge.

Modification of the topography and diversion of flows from one drainage to another obviously could alter the stream flows.

Interruption of Aquifers

Removal of overburden and coal where strata of that overburden or coal are aquifers will intercept ground water flow in a localized area near the mine. This could result in drying up of local shallow wells. Upon replacement of the overburden and spoil, impermeable (clayey) materials might create an area of lower permeability which could destroy a local aquifer in perpetuity. Compaction of the disturbed materials over time will result in surface and subsurface changes from that existing immediately after mining up to about 25 percent of the total thickness of replaced material.

In other circumstances, upon replacement of the overburden, the permeability may be increased through the mined area.

One further possible effect is development of intercommunication of two or more aquifers due to the removal of aquicludes. This could be especially notable if saline or otherwise adverse ground water communicates with a fresh water.

Oil Fields

The possibility exists that abandoned or active oil or gas fields would coincide with economically mineable coal fields. If care were not taken to avoid disturbance of plugged wells (or active wells), blowouts or oil seeps into the mining are would occur. The blowout could result in the possible pollutants of oils and/or brines entering the mining pits and ultimately into fresh water aquifers or surface waters. Appendix II-VIII contains oil field maps of Wyoming and Montana. The Gillette, Wyoming area and generally northeast Wyoming represents the highest probability of mutual occurrence of strippable coal with oil and gas fields. The Williston Basin primarily within North Dakota and the Cedar Creek Gas Field and Belle Creek-Wright Creek Fields in Montana represent other areas of coincidence of coal and petroleum.

Generally, adequate protections of existing and abandoned wells have been required, such as the USGS, Oil and Gas Division requirements that wells be cased for 150 feet through coal seams and that they be cemented down to 300 feet in known coal areas.

Trapped Gas

In certain areas pockets of hydrogen sulfide have been encountered immediately beneath the coal seams. Such pockets not only represent a possible occupational hazard, but the gas can become dissolved in waters collected in sumps on the pit floors. Values as high as 46 mg/l of dissolved sulfide (as sulfur) have been reported in the sump discharge of a currently active pit in Northeastern Wyoming. Pockets of methane or natural gas may also be encountered in or beneath coal seams.

Impoundments

It is possible that certain areas of the NGP will have the potential of being reclaimed after coal extraction to include ponds, lakes, or reservoirs. In areas where thick coal seams lay near the surface, a general lowering of the topography is easily visualized as is the potential for proposals to create impoundments. New impoundments may decrease suspended solids contents if located in turbid streams. Impoundments may also silt up quite rapidly. If evaporation prevails, the impoundments may contribute to increases in dissolved solids. In areas of high nitrates and phosphates, the impoundments may become overpopulated with aquatic vegetation and algae. Impoundments may also enhance agricultural use, which may in turn increase agricultural pollution potentials. The same dilemma exists for recreational (fishing, hunting, boating, etc.) use.

c. Water Quality Data

Some data of untested accuracy have been gleaned from selected applications for water discharge permits in the Western States (including Colorado and Utah). Table I-C.4-3 contains that data in the form of results of individual measurements, arithmetic means, and standard deviations. The data represent water collected within the working pit of a coal mine and some surface waters prior to passing the mining operation. In no case can we be certain that the data represent water that has passed through spoils material but rather it appears that many analyses are of water that enters the pit through the working face of the mine and generally through the coal.

The data of Table I-C.4-3 show the possibility that selected elements such as iron, suspended solids, aluminum, lead, etc. may, on occasion, be quite high. The value of 250 ug/l for mercury reported once for mine site "G" is typical of the anomalous values. We feel, however; that to draw conclusions based on these limited data would be, at best, premature. The data should be used only in a qualitative manner.

TABLE I-C.4-5

PRELIMINARY WATER QUALITY DATA* FROM COAL MINES IN NORTH DAKOTA, MONTANA, COLORADO AND UTAH

ppm | µg/l

Mine	Date of Collection		pH	TDS	SS	Ca	Mg	Na	HCO_3	SO_4	Cl	K	NO_3 (as N)	NH_4	B	F	COD	BOD	Al	Cu	Ni	Mn	Fe	Zn	Cd	Cr	Pb
A	1972	Jan	7.3	2962	141	183	22	19	-	1812	4.9	-	0.56	0	-	0.79	8.8	-	600	16	175	82	305	31	15	18	118
		Feb	7.5	3453	0	37	28	180	-	15,728	3.3	-	2.24	0	-	0.66	23.4	-	660	27	140	140	640	18	11	3	210
		Mar	7.2	3362	0	308	256	192	-	1498	8.8	-	1.54	2.1	-	0.06	4.0	-	1210	10	110	66	410	42	10	5	3
		May	7.4	3199	211	266	272	155	-	1646	6	-	0.56	0	-	0.16	9.3	-	280	0	161	25	70	18	-	-	-
		Jun	7.3	3446	400	308	270	136	-	1676	17	-	0	0	-	0.21	9.5	-	150	30	120	52	106	11	-	-	-
		Jul	7.3	2804	127	183	292	183	-	1723	13.5	-	-	-	-	0.12	4.9	-	300	7	190	35	130	9	-	-	-
		Aug	7.4	2711	311	-	-	120	-	1628	22	-	6.3	<0.1	-	0.19	11.7	-	500	10	10	70	155	155	1	0	6
		Sep	7.6	2737	131	262	282	14	-	1498	2.8	-	0.06	1.2	-	0.18	1	-	800	10	345	730	600	60	-	0	0
		Oct	7.7	3016	0	634	246	121	-	1384	11.2	-	0.5	3	-	0.29	4.4	-	2900	10	190	500	3825	11	-	1.2	19.5
		Nov	7.8	2658	28,983	752,000	6110	108	-	1468	14.1	-	2.4	7.2	-	0.27	1055	-	300,000	250	1065	6000	514,000	2,033	3.8	2.7	2000
	1973	Jan	7.5	2474	0	222	248	119	-	4314	13	-	0.2	0.5	-	0.10	0	-	230	10	95	280	250	45	56	17	65
		Feb	7.5	1922	0	148	178	-	-	2996	6.6	-	-	-	-	0.16	0	-	300		-		363	-	-	-	585
		Mar	7.4	-	50	254	127	-	-	3471	-	-	-	-	-	0.21	-	-	1300	-	-	-	-	-	-	-	106
		Apr	7.5	2252	233	160	200	39	-	2295	11	-	1.5	0.4	-	0.16	4	-	500	0	38	40	300	31	77	0	100
		May	7.6	2593	41	161	227	159	-	2157	35	-	0.5	0.5	-	0.24	3	-	100	0	402	60	115	2	71	15	116
		Jun	7.7	2546	8	169	236	152	-	3295	23	-	1.2	0.4	-	0.71	8	-	150	5	264	33	140	133	98	75	1334
		Jul	7.7	2465	8	170	200	118	-	3235	17	-	8.5	2.5	-	0.32	4	-	230	10	179	90	135	2	43	7	115
		Aug	7.5	2441	16	190	237	130	-	3301	60	-	2.5	0.2	-	0.79	0	-	430	0	567	30	313	0	74	16	35
		Sep	7.5	2719	1	180	262	140	-	2906	27	-	1.1	0.3	-	0.70	5	-	500	0	515	90	85	70	90	78	1629
		Oct	7.8	2510	36	52	656	256	-	2037	20	-	1.1	0.7	-	0.79	1	-	650	5	171	215	130	0	64	0	150
Mean & S.D.			7.5 ±0.2	2751 ±408	1534 ±6457	39,764 ±172,470	545 ±1354	130 ±61	-	3053 ±3312	17 ±13	-	1.42 ±2.28	0.89 ±1.79	-	0.26 ±0.21	102 ±766	-	15,754 ±66,416	22 ±58	306 ±274	473 ±1362	27,499 ±117,614	144 ±472	40 ±35	13.8 ±20	300 ±605
Mean w/o Nov, 1972					80 ±120	217 ±127	235 ±132								-		3.5 ±5.1	-	742 ±1257	8.5 ±9.1	285 ±204	168 ±191	471 ±854	38 ±44	-		178 ±453
B	1972	Aug	7.6/7.5	4370/4020	1.8/0.8	164/303	314/214	610/493	642/144	2790/2420	12/13	21/7.2	3.4/7.3	[illegible]	-	1.0/1.2	-		420/150	[illegible]	[illegible]	[illegible]	420/1300	[illegible]	[illegible]	[illegible]	[illegible]
		Oct	8.2/7.7	4766/1502	12/8	248/81	118/26	649/258	512/144	2295/195	33/12	24/8.4	[illegible]	[illegible]		1.2/0.9			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Oct-Nov	8.1/7.5	5060/974	15/27	289/65	331/21	662/243	561/162	[illegible]	36/12	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1973	Jan	-/-	-/373	[illegible]	-/74	-/17	-/266	[illegible]	-/185	-/12	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Mar	[illegible]	2880/1540	[illegible]	[illegible]	154/35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Apr	8.4/7.9	1730/1560	[illegible]	[illegible]	196/59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Jun	[illegible]	3520/1162	66/73	[illegible]	[illegible]	444/281	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Jul	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Aug	[illegible]	[illegible]	168/129	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Sep	[illegible]	[illegible]	[illegible]	[illegible]	541/56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Oct	[illegible]	6380/882	[illegible]	[illegible]	424/75	[illegible]	[illegible]	4090/300	44/11	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Nov	[illegible]	6460/1115	[illegible]	[illegible]	438/39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Dec	[illegible]	6800/597	[illegible]	[illegible]	588/72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1974	Jan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Feb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Mar	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Mar-Apr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Apr-May	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Aug	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean & S.D.			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean w/o Aug, 1972							29±17			195±135																	
C	1972	Jan	-	456						78	5	-	0.71		-	0.74	765	-	4456	22	[illegible]	[illegible]	15,462	[illegible]	[illegible]	-	98
		Feb		492						90	13	-	0.4	[illegible]	-	0.90	[illegible]		[illegible]	[illegible]	[illegible]	14	[illegible]	[illegible]	[illegible]	-	41
		Mar		658						238	20		0.27	[illegible]		0.18	13		597	10	50	16	227	[illegible]	[illegible]		[illegible]
		Apr		539						129	38		0.34	[illegible]		0.47	90		2730	[illegible]	[illegible]	11	2433	[illegible]			[illegible]
		May		475						125	14		0.6	[illegible]	-	0.27	37		1500	[illegible]	[illegible]	30	1345	[illegible]	[illegible]		4.3
		Jun	8.3	517						120	17		0.40	-		0.25	43		[illegible]	[illegible]	[illegible]	20	613	44	[illegible]		[illegible]
		Jul	8.8	451						60	10		0.30			0.25	32		900	[illegible]	[illegible]	15	756	77	[illegible]		68
		Aug	7.6	420						150	15		0.1			1.24	43		350	79	43	30	940	14	[illegible]		[illegible]
		Sep	7.4	387						224	6		1.3	0.1		0.90	11		600	[illegible]	[illegible]	[illegible]	350	40	[illegible]		[illegible]
		Oct		1190						139	41		1.1	1.1		0.42	[illegible]		250	[illegible]	[illegible]	30	135	[illegible]	[illegible]		[illegible]
		Nov	7.2	413						108	27		0.05	[illegible]		0.36	[illegible]		[illegible]	[illegible]	[illegible]	6	153	29	[illegible]		[illegible]
		Dec	8.7	542						180	10		0.1	[illegible]	-	0.25	10			4	30	34	443	[illegible]	[illegible]		[illegible]
Mean & S.D.			7.6 ±.6	592 ±270						149 ±128	19 ±36		0.64 ±0.57	.34 ±.35		0.40 ±0.30	84 ±211		1382 ±1851	6 ±7	41 ±41	41 ±51	1980 ±853	60 ±81	0.11 ±0.44		[illegible] ±25
Mean w/o Jan, 1972																							713 ±674				

ppm

TABLE I-C.4-3 (CONT'D)

PRELIMINARY WATER QUALITY DATA* FROM COAL MINES IN NORTH DAKOTA, MONTANA, COLORADO AND UTAH

Mine	Date of Collection	pH	TDS	SS	Ca	Mg	Na	HCO_3	SO_4	Cl	K	NO_3 (as N)	NH_3	B	F	COD	BOD	Al	Cu	Ni	Mn	Fe
D	1972 Jan	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Feb	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mar	7.0	5274	246	-	-	-	-	2220	36	-	14.4	6.4	-	0.28	6.35	-	1120	30	200	870	97
	Aug	5.5	4123	0	-	-	-	-	2337	4.3	-	2.7	<0.1	-	0.54	37.7	-	550	27	245	140	150
	Sep	5.5	4165	19	-	-	-	-	2367	8.3	-	3.4	0.5	-	0.72	7	-	200	30	135	605	1150
	Oct	5.5	3880	37	-	-	-	-	2397	41	-	4.0	0.6	-	0.45	8.5	-	75	21	320	281	80
	Nov	5.5	3890	-	-	-	-	-	2277	44.5	-	1.0	<0	-	0.46	8.4	-	502	30	250	335	190
Mean & S.D.		5 ±1.5	4262 ±581	74 ±115	-	-	-	-	2320 ±71	19 ±16	-	6 ±6	<1.9 ±3	-	0.49 ±.2	13.6 ±14	-	489 ±426	28 ±4	270 ±56	446 ±291	333 ±458
E	1972 Mar	7.0	1105	0	111	80	74	-	300	6.5	6.4	0	0	-	0.[illegible]	-	-	366	4	230	203	90
	Apr	6.3	1036	71	-	-	-		395	24	-	4.7	-	-	0.48	-	-	1300	9	105	205	1167
	May	7.0	920	28	-	-	-	-	312	11	-	3.0	0	-	0.60	-	-	250	10	135	140	80
	Aug	7.0	990	5	-	-	-	-	285	15	-	2.0	0	-	0.42	-	-	350	5	115	80	215
	Oct	7.0	1002	2	-	-	-	-	509	14	-	3.7	<0.1	-	0.51	-	-	550	0	130	140	955
	Nov	6.9	1055	20	-	-	-	-	285	14	-	6.0	1.4	-	0.47	-	-	200	10	175	95	485
	Dec	6.9	1100	23	-	-	-	-	270	19	-	6	2	-	1.6	-	-	240	10	110	130	558
Mean & S.D.		6.9 ±.3	1041 ±67	21 ±25	-	-	-	-	337 ±88	15 ±5	-	3.9 ±2.8	<2.4 ±2.6	-	0.73 ±0.49	-	-	464 ±388	7 ±4	143 ±41	140 ±50	507 ±424
F	1973	7.8	1170	-	-	-	-	-	316	-	-	-	-	-	1.4	-	-	-	-	-	-	300
	1974 Aug	7.9	808	5	39	32	224	-	164	13	4.1	-	1.5	200	1.4	-	-	120	[illegible]	[illegible]	90	60
G	1973 Oct	-	432 2196	-	-	-	-	-	134 438	-	-	-	-	-	[illegible]	-	-	-	-	-	-	300 [illegible]
	Nov		476 1968	-	-	-	-	-	289 742	-	-	-	-	-	[illegible]	-	-	-	-	-	-	410 [illegible]
	Nov	-	1917	-	-	-	-	-	736	-	-	-	-	-	[illegible]	-	-	-	-	-	-	[illegible]
	Dec	-	1924	-	-	-	-	-	961	-	-	-	-	-	[illegible]	-	-	-	-	-	-	[illegible]
	Dec	7.7	1872	-	-	-	-	-	723	-	-	-	-	-	[illegible]	-	-	-	-	-	-	[illegible]
	Dec	7.7	1792	-	-	-	-	-	702	-	-	-	-	-	[illegible]	-	-	-	-	-	-	[illegible]
	1974 Jan	7.8	1913	-	-	-	-	-	785	-	-	-	-	-	[illegible]	-	-	-	-	-	-	[illegible]
	Jan	7.7	1879	-	-	-	-	-	797	-	-	-	-	-	[illegible]	-	-	-	-	-	-	[illegible]
	May	7.9	2329	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	[illegible]
	May	7.8	1582	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	May	7.9	2216	-	-	-	-	-	785	-	-	-	-	-	-	-	-	-	-	-	-	[illegible]
	Jun	8.2	730	-	-	-	-	-	415	-	-	-	-	-	-	-	-	-	-	-	-	[illegible]
	Jun	7.8	2140	-	-	-	-	-	215	-	-	-	-	-	[illegible]	-	-	-	-	-	-	370
Mean & S.D.		7.6±0.3	1876±395	-	-	-	-	-	602±225	-	-	-	-	-	[illegible]	-	-	-	-	-	-	[illegible]
H	1974 Feb	7.4	724	20	-	60	41	-	361	11	-	-	-	-	[illegible]	-				[illegible]		200
	Mar	7.8	698	11	-	-	-	-	[illegible]	-	-	-	-	-	[illegible]	-	-					200
	Jul	8.1	933	40	-				449	-	-	-	-	-	[illegible]	-	[illegible]	-	-			600
	Aug	[illegible]	1152	7	136	[illegible]	[illegible]	-	341	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]	-	-	200	[illegible]	[illegible]	[illegible]	80
I	1971 Aug	8	1588	4	10	[illegible]	320	445	[illegible]	[illegible]		-	-		[illegible]	-	[illegible]	[illegible]	[illegible]	[illegible]	40	<50
J	1971 Aug	7.8	3113	13	126	[illegible]	690	136	1850	[illegible]	-	-			[illegible]		[illegible]	[illegible]	[illegible]	25	[illegible]	<50
K	1974 Feb	7.7	-	-		-	-		920	[illegible]	-	-	[illegible]		[illegible]	16.4	[illegible]	[illegible]	-	170	[illegible]	120
	Mar	8.1	1966	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	410
	May	7.8	1972	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100

NH_3	B	F	COD	BOD	Al	Cu	Ni	Mn	Fe	Zn	Cd	Cr	Pb	Hg	As	O&G	P	SiO_2	Se	Sr	
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
6.4	-	0.26	6.35	-	1120	30	200	870	97	9	0	9	0	0	-	1.0	0	-	-	-	Surface Mine
<0.1	-	0.54	37.7	-	550	27	245	140	150	105	0	1	0	0	-	0	0.014	-	-	-	
0.5	-	0.72	7	-	200	30	135	605	1150	105	0	0	0	0.02	-	0	0.003	-	-	-	
0.6	-	0.45	6.5	-	75	27	320	281	80	26	0	0	0	0.02	-	-	-	-	-	-	
<0.	-	0.48	8.4	-	502	30	250	335	190	7	0	0	0	0.11	-	-	-	-	-	-	
<1.9 ±3	-	0.49 ± .2	13.6 ±14	-	489 ±405	28 ±4	270 ±56	446 ±291	333 ±458	50 ±50	0	2 ±4	0	.03 ±0.5	-	0.3 ±.6	0.01 ±.01	-	-	-	
0	-	0.88	-	-	360	4	230	203	90	347	17	2	80	0	-	0	0	-	-	-	
-	-	0.48	-	-	1300	9	105	205	1167	74	<1	0	6	0.02	-	-	-	-	-	-	
0	-	0.60	-	-	250	10	135	140	80	78	0.2	0	0	0.06	-	0.68	0	-	-	-	Surface Mine
0	-	0.42	-	-	350	5	115	80	275	0	0	0	0	0.12	-	0	0	-	-	-	
<0.1	-	0.51	-	-	550	0	130	140	955	0	0	0	0	0.05	-	0	0.01	-	-	-	
1.4	-	0.47	-	-	200	10	175	85	485	40	0	0	0	0.02	-	-	-	-	-	-	
2	-	1.8	-	-	240	10	110	130	558	10	2	1	6	0.03	-	-	-	-	-	-	
<2.4 ±2.6	-	0.73 ±0.49	-	-	464 ±386	7 ±4	143 ±45	140 ±50	507 ±424	80 ±424	3 ±6	0.43 ±0.75	13 ±30	0.04 ±0.04	-	0.17 ±0.34	.00 ±.01	-	-	-	
-	-	1.4	-	-	-	-	-	-	300	-	-	-	-	-	-	-	-	-	<10	400	Surface Mine
1.5	200	1.4	-	-	120	<10	<10	80	40	80	<4	<15	<30	<1	30	-	-				
-	-	0.1 $\overline{1.8}$	-	-	-	-			300 $\overline{300}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	0.1 $\overline{1.3}$	-	-	-	-	-	-	400 $\overline{750}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	- $\overline{1.5}$	-	-	-	-	-	-	- $\overline{730}$	-	-	-	-	-	-	-	-	-	-	-	Surface Mine
-	-	- $\overline{1.3}$	-	-	-	-	-	-	- $\overline{630}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	- $\overline{3.4}$	-	-	-	-	-	-	- $\overline{400}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	- $\overline{1.0}$	-	-	-	-	-	-	- $\overline{300}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	- $\overline{3.9}$	-	-	-	-	-	-	- $\overline{500}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	- $\overline{0.7}$	-	-	-	-	-	-	- $\overline{600}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	- $\overline{6500}$	-	-	-	-	-	-	-	-	-	-	-	
-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	- $\overline{300}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	- $\overline{300}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	- $\overline{Tr}$	-	-	-	-	-	-	- $\overline{310}$	-	-	-	-	-	-	-	-	-	-	-	
-	-	- $\overline{1.0±0.3}$	-	-	-	-	-	-	- $\overline{934±1606}$	-	-	-	-	-	-	-	-	-	-	-	
														-	-	30	2	-	-	-	
-	-	0.9	-	-	-	-	50	-	200	2000	300	-	-	-	-	-	2	-	-	-	Surface Mine
-	-	0.35	-	-	-	-	-	-	200	-	-	-	-	-	-	-	<1	-	-	-	
-	-	0.70	-	-	-	-	-	-	620	-	-	-	-	-	-	-	-	-	20	1700	
0.92	<200	0.96	-	-	<100	<10	<10	10	20	190	<4	<15	30	<1	<30	-	-				
-	-	0.1	-	1	10	"0"	25	90	<50	5	"0"	130	13	0.5	-	11	-	-	-	-	Surface Mine
-	-	0.3	-	5.9	12	"0"	25	90	<50	5	13	80	13	250	-	23	-	-	-	-	Surface Mine
0.38	-	0.27	15.9	10	1870	-	100	360	120	80	6	-	20	3	-	4.2	-	-	-	-	Underground Mine
-	-	-	-	-	-	-	-	-	410	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	160	-	-	-	-	-	-	-	-	-	-	-	

TABLE I-C.4-3 (CONT'D)

PRELIMINARY WATER QUALITY DATA* FROM COAL MINES IN NORTH DAKOTA, MONTANA, COLORADO AND UTAH

Mine	Date of Collection	pH	TDS	SS	Ca	Mg	Na	HCO_3	SO_4	Cl	K	NO_3 (as N)	NH_3	B	F	COD	BOD	Al	Cu	Ni	Mn
L	1973 May	8.0	2700	140	-	-	350	-	1466	106	20	-	1.5	-	-	-	-	-	-	-	100
	Nov	8.2	2325	-	255	126	330	634	1150	130	22	-	-	-	-	34.6	-	-	-	-	-
	1974 May													-	-	-	-	-	<10	-	30
	Aug	8.0	2238	104	216	150	262	-	1087	58	23	-	3.2	<200	0.56	-	-	500	<10	<10	100
M	1974 Jan	7.4	-	6.5	-	-	-	-	555	46	-	0.54	0.39	-	0.60	6	<10	930	-	200	770
	Mar	7.1	1267	38	-	-	-	-	880	-	-	-	-	-	-	-	-	-	-	-	-
	May	8.2	1721	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Jun	8.2	1723	14	-	-	-	-	1033	-	-	-	-	-	-	-	-	-	-	-	-
	Jul	8.6	2043	16	-	-	-	-	1190	-	-	-	-	-	-	-	-	-	-	-	-
	Aug	8.0	3212	18	184	225	175	-	-	81	24	-	4.8	<200	0.89	-	-	270	<10	<10	100
Mean & S.D.		7.9 ±0.6	1993 ±735	16 ±12	-	-	-	-	914 ±271	-	-	-	-	-	-	-	-	-	-	-	-
N	1974 Aug	8.4	994	48	14	11	317	-	135	13	28	-	1.3	<200	1.5	-	-	700	<10	<10	10
O	1974 Aug	7.1	2018	168	144	35	438	-	1130	39	4	-	1.9	<200	0.67	-	-	100	<10	<10	60
P	1974 Aug	8.2	3036	22	320	170	17	-	75	430	4.7	-	0.47	<200	3.5	-	-	<100	<10	<10	60
Q	1973 Oct	7.2/7.4	19/2482	50/1.3	24/320	7.6/50	1.4/21	-	<1/1300	<1/8.0	<1/3.2	-	-	-	-	-	-	<100/<100	<100/<100	-	<50/50
	Nov	7.5/8.1	160/2500	-	31/360	8.8/46	1.2/25	-	24/400	<1/4.8	<1/5.7	-	-	-	-	-	-	<100/<100	<100/<100	-	<50/60
	Dec	7.7/7.4	100/2300	-	36/370	8.9/160	1.1/21	-	42/460	<1/5.0	1/4.8	-	-	-	-	-	-	<500/600	<10/<10	-	10/340
	1974 Jan	7.7/7.9	100/2300	-	32/380	8.1/150	1/20	-	64/<800	<1/<7100	<2/4.7	-	-	-	-	-	-	<500/<500	<10/<10	-	<10/380
	Feb	7.6/7.8	130/-	-	37/380	10/180	1.1/19	-	130/<800	1.1/5.0	<2/4.0	-	-	-	-	-	-	<500/<500	-	-	<10/380
	Mar	7.9/7.4	-	-	-	-	-	-	5/<400	1/3	<2/3.7	-	-	-	-	-	-	-	-	-	<20/410
	Aug	8.0	2646	52	320	175	16	-	1100	8.8	4.7	-	1.8	<200	0.31	-	-	100	<10	<10	40
	Aug	7.8	4994	34	504	350	57	-	2990	7.9	23	-	-	200	0.29	-	-	<100	<10	40	30
Mean & S.D.		7.6±0.2/7.7±0.3	104±53/2870±1049	-/29±26	32±5/376±62	8.7±0.9/153±101	1.1±0.1/26±78	-	44±48/<1,044±822	<1±0.1/<17.6±33.4	1.5±0.6/6.7±6.6	-	-	-	-	-	-	<340±219/<286±234	<55±52/<40±47	-	<25±20/209±17
R	1974 Aug	7.9	3200	28	408	185	56	-	1451	10	5.7	-	1.9	<200	0.31	-	-	100	<10	30	30
S	1974 Aug	7.7	1600	34	100	89	360	-	665	34	18	-	<0.02	<200	1.2	-	-	<100	<10	<10	20
T	1974 Aug	8.3	1004	76	14	10	330	-	75	91	3.7	-	<0.02	<200	1.4	-	-	200	<10	<10	20
U	1974 Aug	8.0	2634	2	192	195	266	-	1330	26	19	-	<0.02	<200	0.46	-	-	<100	<10	<10	10
V		7.6	613	11	-	-	-	-	200	7.3	-	0.4	0.2	-	-	-	-	-	-	-	-
W	1974 Aug	8.0	2048	10	180	145	49	-	130	5.5	13	-	2.1	<200	0.52	-	-	<100	<10	<10	<10
X	1974 Feb	8.2	756	-	60	60	57	423	155	3.0	-	0.43	-	-	0.42	-	-	-	-	-	520
	Feb	7.8	315	-	75	23	22	170	64	2.5	-	6.1	-	-	0.21	-	-	-	-	-	-
Y	1974 Aug	7.7	5475	4	248	165	880	-	2500	21	13	-	2.0	<200	0.68	-	-	<100	<10	<10	90
	Aug	7.9	4358	12	400	475	820	-	3700	23	16	-	2.9	<200	0.90	-	-	<100	<10	40	60
Z	1974 Aug	7.4	2922	6	256	130	258	-	1200	18	23	-	1.5	<200	0.19	-	-	<100	<10	<10	170
	Aug	7.7	1888	2	144	95	157	-	660	9.7	21	-	1.4	<200	0.15	-	-	<100	<10	<10	20
	Aug	7.7	1288	<1	124	85	98	-	360	6.4	20	-	2.1	300	0.17	-	-	<100	<10	<10	120

Note: A/B

A Samples from upstream of mine

B Samples from mine (pit) discharge to stream downstream of A

* Water Quality Data - (all data assumed to represent total measurement where not designated. No quality control data available to authors. Data obtained from water discharge permit applications and independent investigations.

NH_3	B	F	COD	BOD	Al	Cu	Ni	Mn	Fe	Zn	Cd	Cr	Pb	Hg	As	O&G	P	SiO_2	Se	Sr	
1.5	-	-	-	-	-	-	-	100	700	-	-	-	-	-	-	-	-	14	-	-	
-	-	-	34.6	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	Surface Mine
	-	-	-	-	-	<10	-	30	600	<20	<1	<10	<10	-	<7	-	-	-	-	-	
3.2	<200	0.56	-	-	500	<10	<10	100	470	250	<4	<10	<30	<1	<30	-	-	-	<10	2200	
0.39	-	0.60	6	<10	930	-	200	770	10	-	-	-	-	-	-	4.2	-	-	-	-	
-	-	-	-	-	-	-	-	-	140	-	-	-	-	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	-	50	-	-	-	-	-	-	<2	-	-	-	-	Surface Mine
-	-	-	-	-	-	-	-	-	60	-	-	-	-	-	-	13.4	-	-	-	-	
-	-	-	-	-	-	-	-	-	90	-	-	-	-	-	-	7.4	-	-	-	-	
4.8	<200	0.89	-	-	270	<10	<10	100	70	120	<4	<10	<30	<1	<30	-	-	-	20	2700	
-	-	-	-	-	-	-	-	-	68 +43	-	-	-	-	-	-	6.8 +5.0	-	-	-	-	
1.3	<200	1.5	-	-	700	<10	<10	10	1300	560	4	<10	<30	<1	<30	-	-	-	30	350	Underground Mine
1.9	<200	0.67	-	-	100	<10	<10	60	860	140	<4	<10	<30	<1	<30	-	-	-	50	3700	Underground Mine
0.47	<200	3.5	-	-	<100	<10	<10	40	200	220	<4	<10	<30	<1	<30	-	-	-	20	1600	Underground Mine
-	-	-	-	-	<100/<100	<100/<100	-	<50/50	290/210	<5/13	-	-	<45/<45	-	-	-	-	-	-	-	
-	-	-	-	-	<100/<100	<100/<100	-	<50/60	-	10/70	-	-	<100/<100	-	-	-	-	-	-	-	
-	-	-	-	-	<500/600	<10/<10	-	10/340	-	24/94	-	-	<160/<160	-	-	-	-	-	-	-	
-	-	-	-	-	<500/<500	<10/<10	-	<10/380	-	<5/40	-	-	<140/<140	-	-	-	-	-	-	-	Surface Mine
-	-	-	-	-	<500/<500	-	-	<10/360	-	<5/40	-	-	<100/<100	-	-	-	-	-	-	-	
-	-	-	-	-	-	-	-	<20/410	-	-	-	-	<100/<100	-	-	-	-	-	-	-	
1.8	<200	0.31	-	-	100	<10	<10	40	300	140	<4	<10	<30	<1	<30	-	-	-	70	1600	
-	200	0.29	-	-	<100	<10	40	30	90	220	<4	<10	<30	3.5	<30	-	-	-	50	12,000	
-	-	-	-	-	<340+219/<286+234	<55+52/<40+47	-	<25+20/205+176	-/200+105	<10+9/88+72	-	-	<108+40/<88+89	-	-	-	-	-	-	-	
1.9	<00	0.31	-	-	100	<10	30	30	70	400	<4	20	<30	<1	<30	-	-	-	<10	4800	Surface Mine
<0.02	<200	1.2	-	-	<100	<10	<10	20	2100	70	<4	<10	<30	<1	<30	-	-	-	30	420	Underground Mine
<0.02	<200	1.4	-	-	200	<10	<10	20	1400	90	<4	<10	<30	1.1	<30	-	-	-	50	30	Underground Mine
<0.02	<200	0.46	-	-	<100	<10	<10	10	90	80	<4	<10	<30	-	<30	-	-	-	40	3900	Underground Mine
0.2	-	-	-	-	-	-	-	-	83	-	-	-	-	<0.5	-	-	<0.1	-	-	-	Underground Mine
2.1	<200	0.52	-	-	<100	<10	<10	<10	60	160	<4	<10	<30	<1	<30	-	-	-	30	1800	Surface Mine
-	-	0.42	-	-	-	-	-	520	-	-	-	-	-	-	-	-	-	-	-	-	
-	-	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Surface Mine
2.0	<200	0.68	-	-	<100	<10	<10	90	30	40	<4	<10	<30	<1	<30	-	-	-	40	6600	Surface Mine
2.9	<200	0.90	-	-	<100	<10	40	60	50	10	<4	<10	<30	<1	<30	-	-	-	10	10,000	
1.5	<200	0.19	-	-	<100	<10	<10	170	150	590	<4	<10	<30	<1	<30	-	-	-	60	4800	
1.4	<200	0.15	-	-	<100	<10	<10	20	130	30	<4	<10	<30	<1	<30	-	-	-	<10	2400	Surface Mine
2.1	300	0.17	-	-	<100	<10	<10	120	160	40	<4	<10	<30	<1	<30	-	-	-	<10	1700	

data assumed to represent total measurement where control data available to authors. Data obtained applications and independent investigations.

I-C.5 Water Quality Characteristics of Municipal Waste

a. Introduction

Increased production of municipal waste appears to be a certain result of increased coal development in the Northern Great Plains. One of the most common uses of water in our modern society is for removal of these wastes. Consequently, the impact on the water and aquatic resources of this region from increased municipal waste discharges as a direct consequence of coal-energy development must be considered.

Municipal wastes can be divided into two major groups, domestic sewage and industrial sewage. The characteristics of these two types of sewage can be very different.

b. Domestic Sewage

The household wastes from a principally residential area are defined as domestic sewage. The characteristics of domestic sewage vary little from one residential area to another.

Average sewage flows from residential areas are approximately 50 gallons per capita per day. If such items as garbage disposals, automatic dishwashers, and automatic clothes washers are prevalent in the residential areas, the sewage flow can rise to 75 gallons per capita per day. This figure can be drastically raised if storm drains are connected to the sewer system or if the sewers are in poor condition allowing a large amount of infiltration into the system.

Domestic sewage is made up of both organic and inorganic compounds. The inorganic compounds present are determined largely by the characteristics of the domestic water supply and the infiltration water.

The organic compounds can be divided into three major groups: proteins, carbohydrates and fats. The organic contribution of sewage is measured in terms of the 5-day biochemical oxygen damand (BOD). It is the measurement of the oxygen required to stabilize the organic matter in sewage by microorganisms. The average per capita contribution of BOD is approximately 0.15 lb/day.

In addition to the chemical compounds present, sewage is also an excellent microbiological medium. Microorganisms may either enter the sewage at its source or enter from the soil due to infiltration. Virtually every type of microorganism may be present in sewage.

c. Industrial Wastes

The wastes from industries discharged into municipal sewer systems consist of sanitary sewage, process wastes and cooling waters. The volume of sanitary sewage is dependent upon the number of employees, and its characteristics would usually be similar to normal domestic wastes.

Process wastes can be divided into two categories: organic and inorganic process wastes. Industries which are normally associated with inorganic process wastes, the metallurgical industry, the inorganic chemical industry, etc., are not now commonly found within the study area, but could be depending upon the level and economics of future development.

The major discharges of industrial wastes to the municipalities within the study area are organic process wastes, primarily those associated with the food processing industry. Packing plants, dairies, sugar beet, and potato processing operations are among the most common food processing operations found in the Northern Great Plains study area. The primary source of organic wastewater within these industries is from cleaning and washing operations. The characteristics of the wastewater are highly variable, but the 5-day BOD may be as high as 2500 mg/l.

Cooling water from these industries does not normally create any serious waste treatment or water quality problems.

d. Water Quality Problems

There are a number of water quality problems caused by discharges of treated domestic waste to streams within the study area. The water quality problems are confined to those stream segments which, due to natural causes or man-made diversions, exhibit low flow conditions during certain periods of the year. The wastewater discharges from the treatment systems described in the previous discussions, although partially treated before discharge, are still capable of creating a number of water quality problems.

The problems most often associated with discharges of treated domestic wastewater are: (1) reductions in the dissolved oxygen of the receiving water, (2) toxicity due to ammonia and chlorine, (3) nuisance growths of aquatic organisms as the result of enrichment of the receiving water, and (4) possible contamination of the receiving water with pathogenic organisms. Each of these problems or potential problems will be covered in detail in the following discussion.

Dissolved Oxygen

During period of low flow the stream may be unable to assimilate the organic matter contained in the wastewater discharges. If the reaeration capacity of the receiving water is not sufficient to supply the oxygen necessary to stabilize the organic matter, the dissolved oxygen content of the stream will be reduced, causing changes in the ecosystem of the stream. The degree of change is dependent upon the amount of reduction in dissolved oxygen that occurs. The oxygen requirements for fish egg development are usually the most critical, therefore the first noticeable change in the ecosystem will be a reduction in fish production. As oxygen levels decrease, the less tolerant fish and other aquatic organisms will be eliminated until only those organisms which can tolerate low dissolved oxygen conditions are present. If the dissolved oxygen is completely depleted, severe odor and nuisance will develop.

In summary, it can be stated that any reduction in dissolved oxygen will reduce the ability of the aquatic organisms to meet the demands of their environment.

Ammonia Toxicity

Ammonia results from the decomposition of organic matter and is normally present in the discharges of municipal wastewater treatment plants in amounts toxic to fish and other aquatic organisms. Treatment plant effluents can contain ammonia concentrations of from 3 to over 20 mg/l, with discharges from lagoons usually containing smaller amounts of ammonia than discharges from mechanical treatment plants. The removal of ammonia is both difficult and expensive and is not employed at any minicipal waste treatment plants within the study area at the present time. Therefore, unless there is sufficient dilution available in the receiving water to lower the ammonia concentrations below the toxic level, damage to fish and other aquatic organisms may occur.

Chlorine Toxicity

Chlorine is a strong disinfectant and is widely used in the disinfection of sewage treatment plant effluents. In the past, little consideration was given to the adverse impact this compound had upon the receiving water. Recent investigations have shown that chlorine compounds are toxic to aquatic organisms in very small concentrations. Effluents from mechanical wastewater plants are more often chlorinated than lagoon effluents since the natural die-off in time of pathogenic organisms in lagoons may be sufficient to meet public health requirements. Alternate means of disinfection, as well as methods to treat chlorinated effluents, are available and may be necessary in more highly populated areas to protect the aquatic life.

Nutrient Enrichment of Lakes and Rivers

Nutrients present in domestic wastewater discharges can result in a number of undesirable changes in the lakes and rivers which receive these discharges. The nutrients present in domestic wastewater, primarily nitrogen and phosphorus, are essential to the growth and reproduction of aquatic plants and other aquatic organisms. If lakes and rivers become artificially and continuously enriched by discharges of treated domestic waste, nuisance growths of aquatic organisms may occur to a point where the beneficial uses of the waters are impaired. Heavy growths of aquatic weeds and algae interfere with boating, fishing and swimming and the oxygen demand of the decaying organic matter may decrease the oxygen content of the receiving water to a point where fish and other desirable aquatic organisms are unable to survive.

Treatment processes which remove nutrients are available, although very expensive, and will be necessary in some areas to protect the beneficial uses of the receiving water.

Pathogenic Organisms

Streams and lakes should be sufficiently free of pathogenic organisms so as not to pose a hazard to health through infections. Certain levels of bacterial quality are required to insure that these health requirements are met. To achieve these levels, disinfection of sewage treatment plant effluents may be necessary. Within the study area, effluents from mechanical treatment plants are usually disinfected, prior to discharge; lagoon effluents normally are not. Due to the long detention times in the lagoons, it has been felt that the natural die-off of pathogenic organisms is sufficient to protect the receiving water and disinfection is not necessary. Where disinfection is practiced, chlorine compounds are the most common disinfection agents.

I-C.6 Trace Elements in the NGP

Coal contains many elements in trace concentrations. Some of these elements are part of the sediment mixed into the coal before burial, others were inherent to the original vegetation and others were absorbed or concentrated after burial. The fate of these elements during the conversion of coal into energy has been the subject of considerable discussion, but is far from being thoroughly understood. There are two questions concerning the fate of trace elements in the conversion process. The first concerns what happens to the elements in the conversion process. The second concerns the changes in the trace element content of the waters, soils, and biota that occur in the environs of coal conversion facilities and their environmental effects. The water quality subgroup is involved in two projects relating to trace elements from coal conversion.

In addition to increasing the trace element monitoring at USGS stations, the water quality subgroup arranged for suites of samples to be collected in the environs of two coal fired power plants in the NGP area and for the samples to be analyzed for the trace elements. Samples have been collected upstream and downstream of the plant in the receiving waters, and from various process streams in the plant. This process will be repeated at least twice. Preliminary data are contained in Table I-C.6-1.

At these same two plants, in addition to a third plant, a chemical mass balance will be conducted around the boiler to help understand where the trace elements in coal go. Quantitative analyses will be conducted for those elements in Table I-C.6-2; semi-quantitative analyses will be done for those elements in Table I-C.6-3. This latter effort is conducted by the Atmospheric Aspects Work Group.

These two programs will considerably advance the knowledge of which trace elements should be monitored or controlled at power plants. Coupled with long term ambient monitoring in streams, data needed for an adequate understanding of trace elements is slowly being collected.

Appendix VI is a report on natural trace element occurrences in northwestern South Dakota. Noteworthy are the high selenium concentrations measured.

TABLE I-C.6-1

RESUL

TWO STEAM

LOCATION	DATE OF COLLECTION	ALUMINUM D*	ALUMINUM T	BARIUM D	BARIUM T	BERYLLIUM D	BERYLLIUM T	BISMUTH D	BISMUTH T	BORON D	BORON T	CADMIUM D	CADMIUM T	CHROMIUM D	CHROMIUM T	COPPER D	COPPER T	COBALT D
(A) North Platte River upstream of power plant	11/18/74	12	3000	66	100	0	0	<3	<3	60	80	0	<10	<3	<3	2	4	<3
(B) North Platte River downstream of power plant	11/18/74	26	92	62	70	0	0	0	0	65	66	0	<10	<3	<3	2	4	<3
(C) Ashpond A	11/18/74	9000	10000	60	170	<2	<2	<6	<6	1400	1400	0	<10	30	30	2	4	<6
(D) Ashpond B	11/18/74	260	1900	84	100	<6	<6	<24	<24	2900	2500	1	20	<24	30	2	60	<24
(E) Scrubber pond	11/18/74	4400	14000	210	610	<5	<5	<21	<22	4100	4400	1	10	1[illegible]	34	35	56	<21
(F) Scrubber clearwell	11/18/74	800	2200	230	220	<5	<5	<22	<21	3800	4300	1	10	<22	<22	30	25	<2
1 Square Butte Creek - Center	5/13/74	150	2800	110	130	0	2	0	0	120	140	<5	<5	0	10	3	3	<3
	9/27/74	20	360	85	92	<2	<2	<5	<5	150	160	<10	<10	<5	<5	4	1	<5
2 Tributary to Square Butte Creek	5/13/74	160	320	120	120	0	0	0	0	180	180	<7	<7	6	2	<3	<3	<3
5 Tributary to Square Butte Creek	5/10/74	100	300	130	140	0	0	0	0	330	350	<7	<7	0	1	5	<4	<3
9 Square Butte Creek at Nelson Lake inlet	5/13/74	170	2300	140	170	0	2	0	0	180	200	<7	<8	1	11	<3	4	<3
	9/26/74	30	320	120	120	<2	<2	<6	<6	200	190	<10	<10	<6	<6	5	1	<6
3 Square Butte Creek discharge from Nelson Lake	5/13/74	75	430	110	110	0	0	0	0	140	200	<6	<6	5	2	<3	<3	<3
	9/27/74	30	480	95	97	<2	<2	<5	<5	190	180	<10	<9	<5	<5	2	1	<5
7 Ashpond discharge	5/10/74	200	18000	210	1400	0	10	0	0	300	560	<4	5	0	50	4	20	<4
	9/26/74	760	2400	170	250	<4	<4	<10	<10	2000	2400	<20	<20	<10	<10	8	13	<11
8 Nelson Lake	5/10/74	170	1500	130	160	0	1	0	0	200	250	<4	<4	0	6	5	5	<3
	9/26/74	80	1100	200	230	<2	<2	<4	<4	300	370	<8	<8	<4	<4	5	4	<5
6 Nelson Lake	5/13/74	130	3300	130	170	0	3	0	0	200	220	<4	<5	0	12	4	5	<3
	9/26/74	60	720	190	210	<2	<2	<4	<4	280	320	<8	<8	<4	<4	5	4	<5
4 Nelson Lake outlet	5/13/74	140	2400	130	160	0	1	0	0	200	250	<4	<5	2	10	4	5	<3
	9/26/74	70	530	190	210	<2	<2	<4	<4	270	340	<8	<8	<4	<4	5	4	<

* D T Dissolved and Total ** picocuries/liter

S OF CHEMICAL ASSAY OF SAMPLES COLLECTED FROM LOCATIONS IN THE VICINITY OF LECTRIC POWER PLANTS IN THE NORTHERN GREAT PLAINS COAL REGION - PRELIMINARY DATA

	GALLIUM		GERMANIUM		IRON		LEAD		LITHIUM		MANGANESE		MOLYBDENUM		NICKEL		STRONTIUM		SILVER		TIN		TITANIUM		VANADIUM		
T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D
<3	<2	<2	<3	<4	7	1600	<3	3	30	36	37	83	3	2	<3	<3	0	0	590	530	<3	<3	<3	100	<3	4	<10
<3	<2	<2	<3	<3	8	570	6	7	30	30	22	45	3	3	<3	<3	0	0	500	620	<3	<3	<3	25	<3	3	<10
<6	20	20	<6	<6	<3	200	<6	<6	18	18	10	15	48	45	<6	<6	<0.6	<0.6	2100	2200	<6	<6	<6	40	70	70	<17
<24	<11	<11	<24	<24	<11	500	<24	<24	18	24	40	50	120	140	<24	<24	<3	<3	9400	9400	<24	<24	<24	110	27	37	<80
<22	<10	16	<23	<24	<10	2400	<21	<22	150	150	640	660	96	96	20	25	<3	<3	5000	4800	<21	<22	<21	540	340	350	10
<21	<10	<10	<22	<21	<10	210	<22	<21	150	140	500	570	100	100	<22	<21	<3	<3	4700	4800	<22	<21	<22	33	300	300	7
<3	<5	<5	<10	<10	56	2300	4	20	26	40	230	180	2	3	<7	8	<1	<1	650	680	<7	<7	<5	940	<7	<7	<1
<5	<2	<2	<5	<5	48	300	20	<5	40	39	7	76	<1	<1	<5	<5	0	0	680	660	<5	<5	<5	10	<5	<5	<1
<3	<7	<7	<15	<15	100	300	3	3	34	32	27	95	1	1	<11	<11	<2	<2	1000	1000	<10	<10	<7	17	<10	<10	<1
<3	<7	<7	<15	<15	90	450	4	5	39	41	<7	160	2	2	<11	<11	<2	<2	720	720	<11	<11	<7	<7	<7	<7	
<4	<7	<7	<14	<16	90	2100	3	7	38	47	120	250	2	4	<10	17	<2	<2	830	1000	<10	<11	7	880	<10	20	
<6	<2	<2	<6	<6	28	500	7	<6	50	48	510	180	2	2	<6	<6	0	0	940	930	<6	<6	<6	14	<6	<6	
<3	<6	<6	<13	<13	33	700	3	2	30	28	150	170	2	2	<7	<7	<2	<2	310	800	<9	<9	<1	25	<6	<6	
<5	<2	<2	<5	<5	25	530	<5	<5	31	31	30	190	2	1	<5	<5	0	0	900	880	<5	<5	<5	14	<5	<5	
6	<4	<6	<9	<13	70	20000	2	18	21	26	55	240	6	18	<5	24	0	<2	785	1400	<6	<9	<4	760	<4	30	
<11	<4	<4	<11	<11	25	2000	<10	<10	70	64	200	340	45	43	<10	10	<1	<1	7500	6540	<10	<10	<10	50	<10	10	
<3	<4	<4	<9	<9	56	1100	5	5	19	20	<4	190	4	5	<6	<6	0	0	530	540	<6	<10	<4	90	<4	<4	
<5	<2	<2	<5	<5	16	780	<4	<4	27	30	7	60	6	5	<4	<4	0	0	720	740	<4	<4	<4	30	<4	<4	
<4	<4	<5	<9	<9	85	2000	4	8	20	21	<4	140	4	[illegible]	<6	7	0	<1	[illegible]	530	<9	<7	<4	120	<4	<7	
<5	<2	<2	<5	<5	20	240	<4	<4	27	28	10	10	3	4	<4	[illegible]	0	0	640	680	<4	<4	<4	20	<4	<4	
<3	<4	<4	<9	<9	80	1700	4	10	19	21	<4	120	4	4	<1	9	0	0	540	560	<6	<9	<4	360	<4	10	
<5	<2	<2	<5	<5	9	300	<4	10	28	30	<3	40	5	5	<4	<4	0	0	770	770	<4	<4	<4	10	<4	<4	

CINITY OF
ELIMINARY DATA

(ELEMENTS in ug/l except RADIUM)

TITANIUM		VANADIUM		ZINC		ZIRCONIUM		URANIUM	RADIUM **	ARSENIC		FLUORIDE		MERCURY		SELENIUM		ANTIMONY		CERIUM		LANTHANUM		YTTERBIUM		YTTRIUM	
D	T	D	T	D	T	D	T	D	D	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T	D	T
<3	100	<3	4	<10	<10	<5	<5	--	0.21	5	-	0.0	0.4	0.0	-	5	7	-	-	-	-	-	-	-	-	-	-
<3	25	<3	3	<10	<10	<5	<5	10	0.12	5	-	-	0.6	0	-	7	7	-	-	-	-	-	-	-	-	-	-
<6	40	70	70	<17	<17	<8	<8	0.8	0.1	3	-	-	0.6	0.0	-	4	7	-	-	-	-	-	-	-	-	-	-
<24	110	27	37	<80	<80	<30	<36	11	0.08	3	-	-	1.4	0.0	-	6	250	-	-	-	-	-	-	-	-	-	-
<21	540	340	350	100	110	<31	<33	7.8	0.05	2	-	-	11.	0.0	-	220	7	-	-	-	-	-	-	-	-	-	-
<22	33	300	300	75	71	<32	<32	11	0.13	0	-	-	9.1	0.0	-	130	180	-	-	-	-	-	-	-	-	-	-
<5	940	<7	<7	<10	10	2	8	0.92	0.13	0	1	0.5	0.9	0.1	0.1	2	2	<5	<7	<45	<45	<6	<7	<0.3	<0.3	<2	<2
<5	10	<5	<5	<15	<15	<7	<7	0.85	0.21	2	2	0.3	0.5	0.1	0.2	0	0	-	-	-	-	-	-	-	-	-	-
<7	17	<10	<10	<15	<15	2	1	1.4	0.05	1	1	0.4	0.5	0.0	0.1	2	1	<5	<5	<45	<45	<6	<6	<0.3	<0.3	<2	<2
<7	<7	<7	<7	<15	<15	4	16	1.8	0.08	0	1	0.4	0.9	0.1	0.1	2	2	<5	<5	<45	<45	<5	<6	<0.3	<0.3	<1	<2
7	880	<10	20	<15	15	2	18	1.5	0.14	0	20	0.4	0.7	0.0	0.0	2	2	<5	<7	<45	<45	<6	<8	<0.3	<0.3	<2	<2
<6	10	<6	<6	<20	<20	<9	<9	1.3	0.08	2	4	0.3	0.8	0.0	0.0	0	0	-	-	-	-	-	-	-	-	-	-
<1	25	<6	<6	<13	<13	1	1	1.7	0.17	0	1	0.5	0.8	0.0	0.0	1	2	<5	<5	<45	<45	<5	<6	<0.3	<0.3	<1	<2
<5	14	<5	<5	<15	<15	<7	<7	2.0	0.14	2	2	0.3	1.2	0.1	0.2	0	0	-	-	-	-	-	-	-	-	-	-
<4	760	<4	30	<10	20	5	50	1.3	0.14	2	5	0.4	0.9	0.0	0.2	1	2	<5	<9	<45	<45	<7	<45	<0.3	1.	<2	10
<10	50	<10	10	<30	<20	<15	<16	4.0	0.06	2	10	1.1	1.8	-	0.1	0	0	-	-	-	-	-	-	-	-	-	-
<4	90	<4	<4	<10	10	13	10	1.3	0.12	0	5	0.6	0.7	0.0	0.2	3	2	<5	<6	<45	<45	<5	<7	<0.3	<0.3	<1	<2
<4	30	<4	<4	<10	10	<6	<6	2.1	0.20	2	4	0.3	1.1	0.0	0.0	2	0	-	-	-	-	-	-	-	-	-	-
<4	120	<4	<7	<10	<10	1	18	1.3	0.11	2	1	0.6	0.8	0.0	0.0	4	2	<5	<7	<45	<45	<5	<9	<0.3	<0.3	<1	<2
<4	20	<4	<4	<10	<10	<6	<6	1.9	0.36	2	3	0.2	1.5	0.0	0.1	0	0	-	-	-	-	-	-	-	-	-	-
<4	860	<4	10	<10	10	2	7	1.4	0.13	0	1	0.5	0.7	0.1	0.1	4	2	<5	<7	<45	<45	<5	<7	<0.3	<0.3	<1	<2
<4	10	<4	<4	<10	<10	<6	<6	1.9	0.21	2	3	0.2	0.9	0.0	0.1	0	0	-	-	-	-	-	-	-	-	-	-

TABLE I-C.6-1 (Cont.)

DESCRIPTION OF SAMPLE COLLECTION CONDITIONS FOR ELEMENTS LISTED

Sample Designation

A: Depth-integrated; discharge 1220 cfs - 42°50'28" and 105°48'06"

B: Depth-integrated; discharge 1240 cfs - at Orpha

C: Grab samples; estimated discharge 50 gpm

D: Grab samples; not flowing

E: Grab samples; precipitate formed despite acidification

F: Grab samples; pond had greenish cast

1. Grab samples

2. Grab samples; 1.4 cfs

3. Depth-integrated (5/13/74); Grab samples (9/27/74); 3.7 and 0.6 cfs

4. Depth-integrated

5. Grab samples

6. Grab samples (5/13/74); Depth-integrated (9/26/74)

7. Depth-integrated

8. Depth-integrated

9. Depth-integrated (5/13/74); Grab samples (9/26/74)

TABLE I-C.6-2

Special Samples Collected from Intake and Discharge of Process Water at a Power Plant (ash, scrubber, and recirculated cooling water) on 11-8-74. Western Coal.

	Element (total concentration, mg/1)													
	Aluminum	Arsenic	Barium	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Molybdenum	Nickel	Uranium	Vanadium	Zinc
Intake	1.8	T*	<0.2	<0.01	<0.01	0.035	1.52	0.055	0.1	0.2	0.025	0.005	0.035	0.55
Effluent	15.8	T	<0.2	0.01	0.02	0.090	15.2	0.025	0.6	0.25	0.075	0.007	0.050	0.85

* Trace

TABLE I-C.6-3

Principal Elements Measured in Mass Balance at Power Plant

- Aluminum
- Antimony
- Arsenic
- Barium
- Beryllium
- Boron
- Cadmium
- Calcium
- Chlorine
- Chromium
- Cobalt
- Copper
- Fluoride
- Iron
- Lead
- Manganese
- Magnesium
- Mercury
- Molybdenum
- Nickel
- Selenium
- Silicon
- Silver
- Sulfur
- Uranium
- Vanadium
- Zinc

TABLE I-C.6-4

Secondary Elements Measured in Mass Balance at Power Plant

Bismuth
Cerium
Gallium
Germanium
Lanthanum
Lithium
Osmium
Palladium
Phosphorus
Platinum
Potassium
Radium
Rhenium
Rhodium
Rubidium
Ruthenium
Scandium
Sodium
Strontium
Tin
Titanium
Thallium
Thorium
Ytterbium
Yttrium
Zirconium

I-C.7 Summary of Important Water Quality Parameters in the NGP

It is often difficult to determine which water quality parameters are the most important to monitor in an effort to assess water quality impacts resulting from coal-energy development orders of magnitude greater than currently present. This difficulty is primarily caused by lack of knowledge about the natural water-land systems and their relationship to man's activities. In addition, the many possibilities for man to mitigate adverse environmental impacts and the possible, and many times unknown, secondary effects which result, leave limited apriori knowledge of adverse impacts.

Based on the possible water quality impacts discussed in the previous sections (I-C.1 - I-C.5), a matrix is developed, shown in Table I-C.7-1, which indicates activities which can have a substantial impact on water quality parameters. The table shows total suspended and dissolved solids potentially impacted by all the activities listed and therefore important parameters to monitor as coal development proceeds. However, this does not indicate that these two parameters are the most critical to maintaining a quality water resource in the NGP. First, total dissolved solids is really only a simple indicator of water quality and the exact salts contributing to dissolved solids are the true indicators of water quality. Other water quality measures, not part of dissolved or suspended solids, may be of far greater significance to ecological, economic, recreational, and health systems.

Aquatic ecosystems are highly dependent upon the nature of the seasonal hydrologic patterns and flows. Chapter III of this report discusses the flows used to make water quality analyses and the resulting tentativeness of the results.

Nutrients, with their problems in causing eutrophication, trace elements, with the many unknowns associated with their impacts, organic materials, with the associated dissolved oxygen problems, and bacteria, if not adequately disinfected, also pose serious water quality questions. Generally these parameters and their effects (DO excepted) are less thoroughly understood, more difficult to analyze, and therefore pose serious questions as to their degree of future impact on water quality.

In the chapter (IV) on water quality impacts of coal development, total dissolved solids and dissolved oxygen impacts will be treated quantitatively for various possible levels of development. The effect on other water quality parameters is treated qualitatively. The reason for this different level of analyses is related to the availability of analytical tools. "Modeling" tools are available for TDS and DO that are effective with the sparse data available and the hydrologic regime of the NGP, while such tools are not available for the other parameters, given our existing data base and knowledge of the system.

TABLE I-C.7-1

Summary of Important Water Quality Parameters for Coal Development in the NGP

	Municipalities	Feedlots	Power Plants	Irrigation	Mines
Physical					
Flow	x		x	x	x
pH					x
Temperature			x		
Suspended Solids	x	x	x	x	x
Chemical					
Nutrients	x	x		x	
Trace Elements			x		x
Salinity (TDS)	x	x	x	x	x
Organic Material (BOD)	x	x			
Biological					
Bacteria	x	x			

I-C.8 Water Quality Impact Prediction

Although impact modeling is in its infancy, it can be utilized for rough estimates of the impact of projected growth or disturbances on a system. The system of concern in this case is the ground and surface water system of the NGP, and the impacting force is the development of surface coal mines and conversion facilities.

The following discussion presents several previously proposed models for sediment yield, dissolved solids yield, and acid-salt formation yield, and some suggestions as to the applicability and utility of those models to the NGPRP study area. The secton goes on to address the modelling of the effects of discharges from coal conversion facilities.

a. Sediment Yield Prediction

Several methods have been proposed for predicting sediment yields from land areas. Because of the number of variables and requirements for relatively large amounts of field data, present predictive methods must be viewed and used with caution. Seciment yield predictions have centered heavily around agriculture activities with more limited applications to wild lands or severely disturbed lands. It is necessary to recognize local variations and conditions when applying predictive formulas. It should also be kept in mind that constant field checking will be necessary to validate any scheme for continued application. However, much of the mining activity may have an impact similar to that from agricultural (crop) activities.

Erosion of surface properties occurs both as (1) sheet and rill erosion and (2) channel-type erosion. The combination of these two types of erosion is known as "gross erosion." Another important term is the "sediment delivery ratio" which is defined as the fraction of soil removed by gross erosion which is delivered to a stream.

A scheme of the necessary steps for predicting the suspended solids concentration in stream at a particular station is outlined below. It is based upon a technique developed by Dissmeyer[1, 2] known as the First Approximation of Suspended Solids (FASS). The steps are as follows:

(1) Stratify (or divide) the study areas using soil types, slope, vegetation, land uses, land disturbances and the quality and type of management.

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1. Dissmeyer, G. E., "Estimating the Impact of Forest Management on Water Quality: Preliminary Procedure", paper presented at Cooperative Watershed Management Workshop, U.S. Forest Service, Memphis, Tennessee, 14 pages, October 4-8, 1971.
2. Dissmeyer, G. E., "Evaluating the Impact of Individual Forest Management Practices on Suspended Sediment", Journal of Soil & Water Conservation, (1973).

(2) Field sample the strata for erosion and sediment production.

(3) Compute erosion and estimated sediment production volumes for each land use or disturbance.

(4) Compute gross erosion and estimated sediment production of the watershed.

(5) Compute storm flow, base flow, and annual flow for the watershed.

(6) Compute average suspended sediment concentrations for the storm, base and annual flows.

The following scheme has been compiled by Andrews[1] and utilizes several techniques and partial models developed by others. This scheme has not been field tested and is outlined as a possible scheme or pattern for developing other schemes.

Prior to entering the computation scheme and characterization of environmental variables is the selection of a study area. The size and character of the area will affect the method or technique to employ.

For small study areas the technique (scheme) is:

(1) Utilize the universal soil loss equation to predict the soil loss in weight/unit area/year from sheet erosion. Calculate the soil loss in monthly increments based on seasonal changes in the erosion index and management factors. (Refer to Appendix II-I).

(2) Utilize Figure I-C.4-1 for estimating the sediment delivery ratio for the study area or utilize data from existing local reservoir sediment deposition surveys if available. (Refer to Appendix II-III).

(3) Estimate channel erosion where information is available through the use of time studies on the advance of gullies. Such information can be obtained through aerial photography and field measurement of selected channels. (See Appendix II-IV).

(4) Calculate the total unadjusted sediment yield by adding the sheet erosion (step 1) and channel erosion (step 3) to obtain gross erosion and then multiply by the sediment delivery ratio (step 2).

(5) Determine the storm, base and annual stream flows from a combination of meteorological and surface water records (USGS). (A good approximation based on research indicates that the proportion of sediment carried during storm flows is within a range of 0.8 to 1.0). (See Appendix II-V).

---

[1] Richard Andrews, personal communication.

(After: U.S. Department of Agriculture, National Engineering Handbook, Section 3, "Sedimentation", USDA - SCS (1973).)

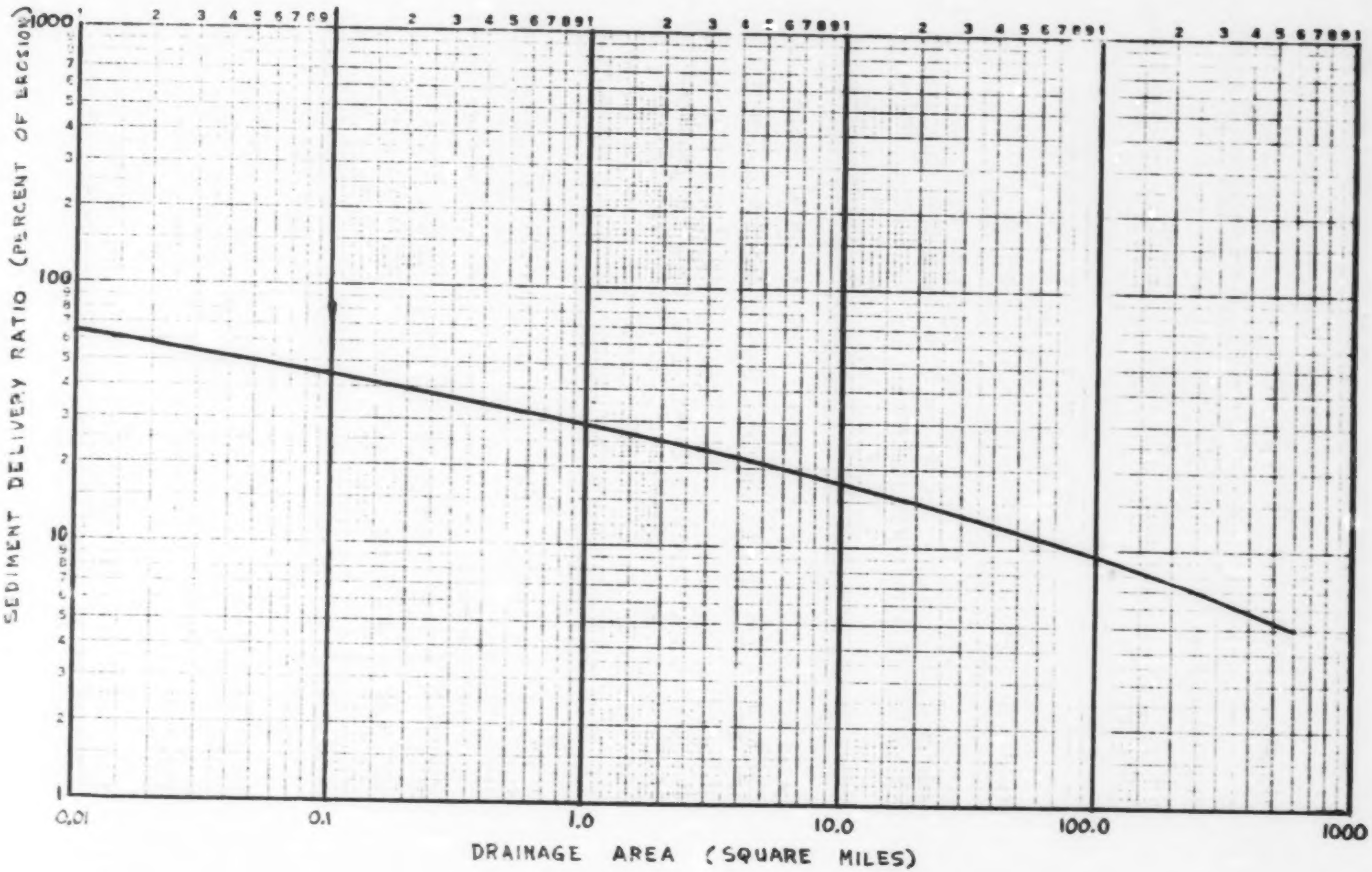


Figure I-C.4-1

(6) Calculate the adjusted sediment yield based upon implementation of major control structures (if utilized) and their associated trap efficiencies for the areas they affect. For approximation purposes use Figure A-II-III in Appendix II-III. More detail may be obtained in reference[1].

(7) Calculate the resulting in-stream concentrations of suspended sediment based upon the values of flows (step 5) and delivered sediment (step 6) for each month during storm and base flow conditions. Annual averages may also be determined.

(8) Where available compare the computed values to sediment data and suspended sediment concentrations at established stream stations.

Other predictive schemes and simulation models for sedimentation and erosion are listed in Appendix II-II, some of which may be poorly suited to the semi-arid environment of the NGPRP study area.

In addition, further refinements could be made, if warranted, in order to relate sediment concentrations to the runoff hydrograph.

Dissolved Solids Yield (From Disturbed Lands) Prediction

The prediction of contributions of dissolved solids from mines or other land disturbances to surface streams is difficult, and few studies have been made that appear to provide accurate prediction techniques. This area is in need of considerable additional research.

There is no doubt that surface disturbances will change the dissolved solids character of water running off of or percolating through the disturbed surfaces. The greatest single influence on the dissolved solids in runoff from disturbed areas is the geochemical nature of the soils or rock within the top 5-12 cm of the soil horizon. Greater depths of soil could influence the runoff if particle sizes and soil water content facilitate upward capillary action and the resulting leaching of salts for deposition on the surface. Other factors which will influence the dissolved solids in runoff include the degree and rate of weathering, pH of the runoff, topographical and meteorological conditions.

Predictive techniques that have been developed are highly specific to the mineralogy of the exposed material such as equations developed for spent oil shale leachate. A few generalizations from that report follow[2] which are based on generalized momentum and mass transport phenomena relationships.

---

1. "Comparative Costs of Erosion and Sediment Control, Construction Activities", U.S. Environmental Protection Agency, EPA-430/9-73-016, pp. 9, 95-102, July 1973.
2. "Water Pollution Potential of Spent Oil Shale Residues", U.S. Environmental Protection Agency, Report 14030 EDB, December 1971.

The concentration of dissolved solids, C, in runoff varies inversely with the mean depth of overland flow, $\bar{D}$, to a power, N.

$$C = \frac{1}{\bar{D}^N}$$

Further C varies directly with the change in surface moisture as follows:

$$C = \exp \frac{(K \quad w)}{(0.435)}$$

where K is a constant and w is the decrease in surface moisture content since the last rain (dimensionless). C decreases with time during any given storm or runoff event. This gives

$$C = \exp \frac{(-t^\gamma)}{(0.435)}$$

in which t is time and γ is a constant. Combining all of the relationships above gives

$$C = \frac{1}{\bar{D}^N} \; f\,(p,\, k) \; \exp \frac{(K \; w - t^\gamma)}{(0.435 \quad)}$$

where K, γ and f (p, k) must be determined experimentally for the system of interest. The function f (p, k) is a relation of the gross density of the surface material, p and the permeability of the surface material, k.

Due to the lack of experimental data necessary to utilize the above model, it has not been pursued.

This concentration on runoff and surface water quality should not result in the conclusion that subsurface flows are unimportant. On the contrary, leaching of minerals into subsurface waters that may affect aquifers or ultimately seep or become bank infiltration to surface waters can be very significant. Modeling the quality of subsurface flows has been investigated extensively in studies of irrigation return flows. Such models have been developed for one-, two- and three-dimensional flow systems and for chemical parameters including NH_4^+, several alkali metals and alkaline earth salts including NO_3^-.

For some simplified models applicable to large basins where individual facilities may be considered point sources refer to Hem[1].

---

[1] Hem, J. D., "Study & Interpretation of the Chemical characteristics of Natural Water", U.S. Geological Survey, WSP-1473, Second Edition, 1970.

The yield of solids may fully be expected to vary seasonally and also with the stage of reclamation attained. As vegetation is reestablished the solids yield may gradually reduce, probably over a 5 to 10 year period in most of the NGPRP area.

Acid Formation Prediction

General relations concerning the potential for pollutants leaching from spoil have been developed based on measurements in Ohio. In general, the study indicates that acid drainage is dependent upon the type of spoil being leached. It should be noted that these generalizations are not generally pertinent to the arid and semi-arid regions of the NGPRP area. The classification system is given in Table I-C.4-3.

TABLE I-C.4-3[1]

Potential For Acid Formation From Spoil Runoff

Spoil Type	Descriptive Characteristics	Produced Acid & Salts, 1st Year tons/acre	Half Life of Pollutant Leach Rate
Toxic	pH < 4.0 on more than 75% of the area	42	3 to 4 years
Acid	pH from 4.0 to 6.9 over 50% of surface	1.5	6 to 8 years
Marginal	50 to 75% of area with pH > 4.0	22	6 to 8 years
Calcareous	pH > 7.0 over 50% of surface area	2	6 to 8 years
Alkaline	Assumed to be pH > 7.0 for greater than 50% of surface	0.6	-------

Models of acid formation based upon knowledge of the nature of the pyritic materials and the bio-physical-chemical environment could be established from studies performed on the fulfide to sulfate reaction mechanism[2] and the influence on that mechanism from such variables as DO, pH, mineral character, biological activity, and presence of various anions and cations[3].

---

[1] Vimmerstedt, J. P. and Struthers, P. H., "Influence of Time and Precipitation on Chemical Composition of Spoil Drainage", paper presented at Second Symposium of Coal Mine Drainage Research, May 14-15, 1968, Pittsburgh, Pennsylvania.

[2] "Sulfide to Sulfate Reaction Mechanism", U.S. Environmental Protection Agency, 14010 EPS 02/70, February 1970.

[3] "Pyritic Systems: A Mathematical Model", U.S. Environmental Protection Agency, EPA-RZ-72-002, November 1972.

Prediction of Pollutants for Other Sources

No analysis or predictive techniques have been attempted or researched for this report based on the other sources of pollution in surface mining of coal.

b. Prediction of Dissolved Solids Impacts of Conversion

The objective of this analysis is to obtain estimates of total dissolved solids concentrations resulting from various levels of development of coal-conversion facilities. These estimates, while certainly not exact, can be used to identify potential problem areas and important mechanisms affecting water quality. While TDS is not the only measure of water quality, it does represent the sum of many important elements which can result in harmful effects (see Appendix I). Total dissolved solids consist, to a large degree, of some common element ions, including bicarbonate, calcium, chloride, magnesium, sodium, and sulfate.

The TDS projections calculated in this analysis are made for a limited number of points along rivers in the NGPRP. These points of analysis are generally located at the mouth of a tributary or at a city on the Yellowstone or Missouri Rivers. These discrete projections of total dissolved solids are considered as the best available estimates given certain assumptions about the natural and man-made forces affecting the TDS system. With a greater understanding of the forcing functions affecting TDS concentrations, and with better quantitative information than is now available, more accurate projections can be made. Until that time, this analysis can serve as an indicator of the relationship of coal and other development to water quality.

In performing this analysis, data must be used which relates future activities to the quantity and quality of water systems found in the Region. Some of these data have been supplied as a result of separate studies and is extraneous in that it is used in this analysis, yet was not designed specifically for that purpose. The manner in which the data were developed and their form does affect the procedure used in our analysis and, consequently, the accuracy of our results.

The hydrologic data used in the analysis in Chapter IV are either the 1970 level monthly flows or the monthly flows projected by water supply studies (see Water Work Group Report, NGPRP). The water supply study flows are used for rivers on which reservoir or aquiduct development is designated as part of the water supply system, and 1970 level flows are used in all other cases. While these flows are not exact, they do reflect the general hydrologic conditions induced by various levels of development and represent the best available information. Stream flows are specifically addressed in Chapter III.

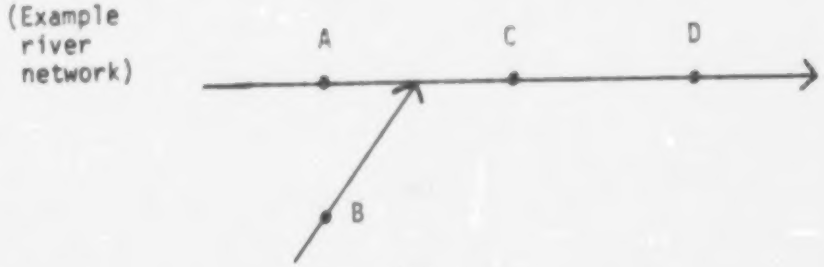
The TDS projections center around the water supply systems designated for each coal development profile projected for year 2000.

These water supply systems are not based first on water quality considerations, but rather on water availability and economics. For each coal development scenario, two water supply systems have been designated as first and second choices. These designated supply systems use aqueducts and reservoirs to supply water to power and gasification plant sites projected for each profile. The TDS analysis is performed only for the "first choice water supply system". Lack of sensitivity of the methodology was the primary reason why additional analysis of other systems is not provided.

The water supply systems which are labeled as being the "first choice" do not represent progressive stages of planning, but instead are choices resulting from the planning of the coal development profile prior to any planning for dam or aqueduct construction. Thus many supply options are available to satisfy the profiles. Since basin water quality impacts, e.g., Tongue River, Powder River, etc., are highly dependent upon the water supply system chosen, it is possible on occasion to show local improvement in TDS concentrations with greater levels of coal development when the water supply system is thus altered drastically from profile to profile. In order to show the cumulative effect on TDS with increasing coal development, an analysis must be performed far enough downstream so that these small basin effects are cancelled out. But, this regional approach does not show the complete picture either. Therefore both basin and regional projections were made in Chapter IV.

In projecting TDS levels, the assumption is made that TDS is a conservative or non-decaying substance in water. This assumption can be made because of the relatively slow reaction rates for the primary TDS constituents. Currently, little is known about the reactions, both chemical and biological, of certain minor elements in natural water systems. But because existing water quality data indicate that these elements are only a small fraction of the total dissolved solids, the assumption appears valid for our present state of knowledge.

Treating TDS as a conservative substance allows for a relatively simple modeling procedure. An equation is used to determine the TDS concentration at point given the significant upstream TDS and flow inputs to the river. The TDS concentrations at two tributary points, A and B, are added in proportion to the flow at A and B to determine the TDS concentration at downstream location C. The input from B could be considered as a discharge from a coal-conversion facility. The calculation is simulated below:



$$(TDS)_C = \frac{(TDS)_A \, Flow_A + (TDS)_B \, Flow_B}{Flow_A + Flow_B}$$

This equation effectively calculates a TDS load.

The concentration at point D farther downstream is either assumed from the period of measurement or could be calculated assuming a constant load from C to D, a constant concentration from C to D, or an incremental increase in load from C to D based upon runoff and recharge characteristics. In all cases in this analysis, the base TDS concentration at point D was taken from historical measurements.

Although variations on this procedure are used in this analysis, all projections are based in theory on this methodology.

c. Methodology Used for DO Analysis

General Approach

The analysis is made by determining the assimilative capacity of the river downstream of the municipal discharge. The assimilative capacity is specified as the amount of waste which will cause the river's oxygen concentration to drop to the appropriate state DO standard for that river. Using the assumptions stated in the previous section, the population that would create such a waste discharge is then determined. This population can then be compared with population projections made for each coal development scenario.

Method of Analysis

A step-by-step explanation of the method of analysis is given below to aid concerned individuals and organization in looking at potential problem areas not analyzed in this report.

Step 1 - Determine the flow characteristics, average depth and velocity, for reaches downstream of the municipality. This requires developing depth-discharge and velocity-discharge relationships for each reach. A reach should be considered a stretch of river with relatively common flow characteristics. The depth- and velocity-discharge relationships can be determined graphically using log-log paper or by fitting the equation below.

$$Y = nQ^m,$$

where Y is the depth or velocity, Q the stream discharge and, n and m are the unknowns. The data needed to determine these relationships are available from the USGS for some locations. The depth, velocity, and discharge data used in this analysis were obtained from the USGS.

Step 2 - Determine the periods or period of the year for which the analysis is to be made. Generally there are two periods of the year which are critical to dissolved oxygen concentration. These periods are during summer low flow months when temperatures are high causing low DO saturation and winter low flows when ice cover causes little, if any, stream reaeration. Also during winter months treatment efficiencies can be lowered, especially for lagoons, causing an increased oxygen demand in the waste. Caution should be taken in analyzing the winter low flow situation since municipal discharges often cause a melt in the ice cover directly downstream of the outlet. Because of this complexity only summer (August) low flow conditions are considered in this analysis.

Step 3 - Determine the flow regime which will be analyzed for the month(s) considered. The lowest average flow for seven consecutive days occurring once in every ten years (7-day, 10-year low flow) is an accepted guideline for analysis of dissolved oxygen impact. This flow can be determined for any month(s) of the year given at least ten years of flow data. In addition to the 7-day, 10-year low flow, this analysis determines the potential impact resulting from future water depletions needed for coal-energy development. Municipalities located along streams or rivers which are designated for possible water resource development are analyzed using Instream Needs Flows (see Chapter III).

Step 4 - Obtain estimates of the parameters defining the characteristics of the oxygen demanding material likely to be discharged into the stream. The assumptions stated earlier defined the per capita waste quantity and the ultimate oxygen demand (UOD) concentration used for this analysis. Other, probably more accurate, estimates can be made when local conditions are known. In making these determinations, certain assumptions must be made about the future level of treatment, future waste characteristics, and per capita waste flows.

Step 5 - Compute or determine from existing data the stream aeration (K_a) and deaeration (K_d) coefficients. When data are not available, these coefficients can be estimated from equations and charts in the many references on this subject. The reference used for this analysis is Simplified Mathematical Modeling of Water Quality, EPA, March 1971.

Step 6 - Determine the mean water temperature for the month(s) being analyzed and apply correction factors to all temperature dependent variables; aeration coefficient, deaeration coefficient, and DO saturation concentration. The dissolved oxygen saturation concentration should also be corrected for altitude.

Step 7 - The solution to the Streeter-Phelps equation is used to calculate the DO response in the river downstream of the municipal waste discharge.

$$D_x = \frac{K_d \cdot L_o}{K_a \cdot K_d} \left[e^{\left(-\frac{K_d \cdot x}{u}\right)} - e^{\left(-\frac{K_a \cdot x}{u}\right)} \right]$$

Where: D_x = DO deficit at $X = x$,

K_d = deaeration coefficient,

K_a = aeration coefficient,

L_o = ultimate oxygen demand at $X = 0$,

U = stream velocity, and

X = distance downstream of discharges

Using this equation the DO response or profile is determined by calculating the DO deficit and subtracting this value plus the background deficit from the saturation concentration to obtain the DO concentration in the stream. These calculations are made at equally spaced intervals downstream of the discharge point. The lowest DO concentration is then compared with the state standard for that location to determine if the river can assimilate the given waste load. If only the lowest DO concentration is needed for the analysis, the equations below provide a faster manner to obtain this result.

$$D_c = \frac{K_d}{K_a} L_o \cdot e^{-\frac{K_d \cdot X_c}{u}} ,$$

$$X_c = \frac{u}{K_a - K_d} \log_e \frac{K_a}{K_d}$$

Where: D_c = maximum DO deficit and

X_c = distance to location of maximum deficit.

Step 8 - Perform a sensitivity analysis by varying the appropriate input parameters within a range of "feasible values". For this analysis the stream depth and velocity are varied according to the depth- and velocity-discharge relationships discussed earlier. Since the methods of estimating the aeration and deaeration coefficients for this analysis are dependent upon the stream depth and velocity, these input parameters were also varied according to "feasible values" of depth and velocity. (For this analysis the phrase "feasible values" means values which are given by or can be extrapolated from the data and not violate the assumptions stated previously.) In addition to these parameters, a range of stream flows may need to be evaluated to account for mixing zones which are less than the total stream flow.

CHAPTER II

WATER USE ALTERNATIVES

No discussion of the impacts of coal development on the water resources of an area, quantity or quality, can be complete without a discussion of how much water is "needed" for coal development. Three separate sections dealing with this subject are presented in Chapter II. Section one of this chapter presents a discussion of how much water is needed for a 1000 MW power plant utilizing wet mechanical draft cooling towers. Section two discusses the economic consequences of utilizing dry cooling towers compared to other techniques. Section three discusses water requirements at coal gasification plants.

II-A Water Requirements for Power Plants With Wet Cooling Towers[1]

How much water does a power plant need to produce electricity? The answer to this question, for power plants located along the Missouri and Yellowstone Rivers and utilizing wet mechanical draft cooling towers, is addressed in this section.

The total power plant water requirements are overwhelmed by the operation of one process--the wet cooling tower system. Goldman and Kelleher[2] cite that over 95 percent of the total plant water usage is for cooling system makeup. The remaining 5 percent satisfies the needs of processes such as: ash handling, pretreatment, condensate treatment, and boiler water treatment. Therefore, the technical and economic factors which affect the cooling system's water requirements are detailed first. Then the 95 percent figure is applied to estimate the total plant requirements. Potential anomolies which can alter the total requirements are discussed. The final product is a range of total water requirements that are possible using available or approachable water conservation and water reuse practices.

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[1] After a paper prepared in cooperation with Guy R. Nelson of the Northwest Environmental Research Center, EPA, Corvallis, Oregon.

[2] Goldman, E. and Kelleher, P. Water Reuse in Fossil-Fueled Power Stations. In: Complete Water Reuse, Cecil, L. K. (ed.). New York, N.Y., American Institute of Chemical Engineers, April 1973. pp. 240-249.

II-A.1 Water Requirements for Wet Cooling Towers

Figure II-A.1-1 is a schematic water flow diagram for a typical wet cooling tower system. The figure identifies the specific cooling system water flows to be studied in this section.

The water quality requirements for water flows shown in Figure II-A.1-1 depend upon three factors:

1. Makeup water quality
2. Plant characteristics
3. Water conservation practices

a. Makeup Water Quality

Water quality data for two selected makeup water sources in the NGP are listed on Table II-A.1-1[1]. Makeup water quality determines the maximum cycles of concentration (cycles) at which the system can operate without water treatment; where the term, cycles, is defined as the number of times that makeup water constituents are concentrated in the recirculating water. The constituents are concentrated due to the evaporation process. As more evaporation occurs, the solubility limits of the constituents are approached. Also, temperature changes that occur in the system affect the solubility of the constituents. If the solubility of one or more of the constituents is exceeded, cooling system fouling may result. Table II-A.1-2 provides some recirculating water quality limitations that are established to minimize fouling[2]. The blowdown serves to keep the recirculating water within the concentration limits.

Maximum Cycles - Tables II-A.2-1 and II-A.2-2 provide data and useful tools for determining the maximum cycles for waters from both sources. It is assumed that the concentrations increase in direct proportion to the number of cycles through the cooling system.

Example - Makeup water from the Yellowstone River has an "Initial" silica concentration of 11.4 mg/l as SiO_2. The maximum cycles, i.e. concentrations, based on silica are,

11.4 X (cycles) = 150 (from Table II-A.2-2)

cycles = 13

The same makeup water has a magnesium concentration of 75 mg/l as $CaCO_3$. Its maximum cycles of concentration based on magnesium and silicate are,

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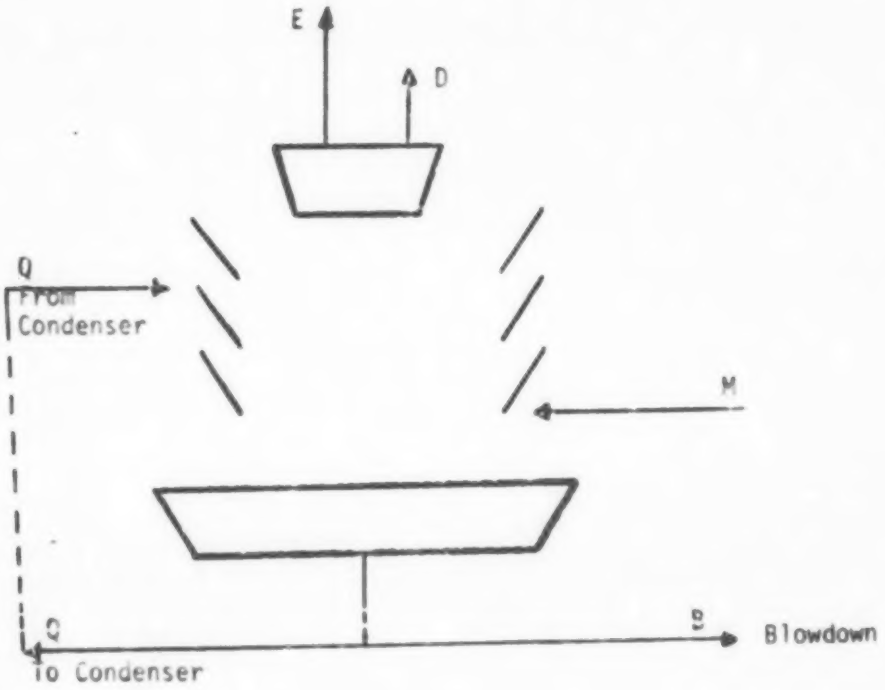
[1] (I-2) STORET - Water Quality Storage and Retrieval System - EPA, January 1974, Mean Values, Period of Record.

[2] (I-3) Reviewing Environmental Impact Statements - Thermal Power Plant Cooling Systems. Thermal Pollution Branch. Corvallis, Oregon Report No. EPA-660/2-73-026. Environmental Protection Agency. 1974. 93 p.

FIGURE II-A.1-1

Wet Cooling Tower System


E
D
Q
From
Condenser
M
Q
To Condenser
B
Blowdown

Where

B = Blowdown rate (m^3/hr)
M = Makeup rate (m^3/hr)
Q = Recirculating rate (m^3/hr)
E = Evaporation rate (m^3/hr)
D = Drift rate (m^3/hr)

TABLE II-A.1-1 MAKEUP WATER QUALITY

Constituent	Concentration (mg/l) Yellowstone River* @ Miles City, MT	 Missouri River* @ Bismark, ND
Total Solids	411	430
Total Dissolved Solids	391	450
Total Hardness as $CaCO_3$	203	212
Calcium as $CaCO_3$	128	128
Magnesium as $CaCO_3$	75	84
Total Alkalinity as $CaCO_3$	150	141
Dissolved Silica as SiO_2	11.4	11.4
Chlorides as Cl	8	8
Sulfates as SO_4	166	172
Dissolved Iron as Fe	0.06	0.03
Dissolved Copper as Cu	-	0.02
pH	7.7 (pH units)	8.4 (pH units)

* These are mean values over a period of record and approximate values given in earlier chapters. Seasonal variations affect design conditions.

TABLE II-A.1-2 RECIRCULATING WATER QUALITY LIMITATIONS

Characteristic	Limitation	Explanation
pH and Hardness	Langelier Saturation Index = 1.0	Langelier Saturation Index = pH -pHs where
pH and Hardness with addition of proprietory chemicals for deposit control.	Langelier Saturation Index = 2.5	pH = measured pH pHs = pH at saturation with $CaCO_3$ See Sisson for nomograph solution[1]
Sulfate and Calcium	$(C_{SO_4}) \times (C_{Ca}) = 500{,}000$	C_{SO_4} = concentration of SO_4 in mg/l C_{Ca} = concentration of Ca in mg/l as $CaCO_3$
Silica	$(C_{SiO_2}) = 150$	C_{SiO_2} = concentration of SiO_2 in mg/l
Magnesium and Silica	$(C_{Mg}) \times (C_{SiO_2}) = 35{,}000$	C_{Mg} = concentration of Mg in mg/l as $CaCO_3$
Suspended Solids[2]	C_{ss} = 400 mg/l	C_{ss} = concentration of ss in mg/l

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[1] Sisson, W. Langelier Index Predicts Waters Carbonate Coating Tendency. Power Engineering. 77:44. February 1973.

[2] Personal communication with B. C. Moore. Betz Laboratories, Inc., Vancouver, WA. December 1973.

$$11.4 \text{ X (cycles)} \quad 75 \text{ X (cycles)} = 35000$$

$$(\text{cycles})^2 = 40.93$$

$$\text{cycles} = 6.4$$

Table II-A.2-3 presents the maximum cycles and corresponding limiting parameters for each location. Both Yellowstone and the Missouri sites are calcium sulfate limited; that is, the lowest values of the maximum cycles correspond to the sulfate and calcium limitation ($SO_4 \times Ca \leq 500,000$).

The makeup, blowdown, and evaporation rates are related to the maximum cycles by equations I-1 and I-2. The equation symbols are from Figure II-A.1-1 and C = cycles.

$$M = BC \qquad\qquad E = B(C-1)$$

The blowdown rate, B, normally includes the tower's drift losses. State-of-the-art design can control drift losses to 0.005 percent of the recirculating rate in mechanical draft towers and 0.002 percent in natural draft towers[1]. Except for very high cycles of concentration (above 20 cycles) this drift loss can therefore be neglected in determining the blowdown rate.

b. Plant Characteristics

The plant characteristics that affect cooling system water requirements are:

a. The plant size (P), in megawatts.

b. The waste heat to cooling water (WH) -- each plant is assigned a waste heat value of 4.622×10^6 KJ/MWH (38% efficiency; kilojoules/megawatt hours) (BTU = 1.0548 KJ).

c. The temperature rise across the condenser (ΔT), °C.

d. The fraction of waste heat discharged by the cooling tower via latent heat vaporization; for estimating purposes, this value is 0.75[1].

e. The heat capacity (C_p) and latent heat of vaporization (L_H) of water for this analysis, the values are $C_p = 4174$ KJ/m^3C° and $L_H = 2.319 \times 10^6$KJ/m^3.

Equations I-3 and I-4 relate these characteristics to cooling system water flow rates, in m^3/hr, of evaporation (E) and recirculation (Q)[1].

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[1] Reviewing Environmental Impact Statements - Thermal Power Plant Cooling Systems. Thermal Pollution Branch. Corvallis, Oregon Report No. EPA-660/2-73-026. Environmental Protection Agency. 1974. 93 p.

TABLE II-A.1-3 MAXIMUM CYCLES OF CONCENTRATION

Water Quality Limitations	Maximum Cycles	
	Yellowstone River Sites	Missouri River Sites
Sulfate and Calcium*	3.7	3.8
Silica	13	13
Magnesium and Silica	6.4	6.0
Suspended Solids	20	20

*Includes SO_4 contribution due to sulfuric acid addition for pH control.

$$E = \frac{0.75(WH)(P)}{L_H} \qquad (I\text{-}3)$$

$$Q = \frac{(WH)(P)}{(\Delta T)(C_p)} \qquad (I\text{-}4)$$

With substitutions of preceding equations into these, one can obtain the following relationships between makeup (M) and blowdown (B) requirements, in m^3/hr, and plant characteristics.

$$M = \frac{0.75(WH)(P)(C)}{L_H\ (C-1)}$$

$$B = \frac{0.75(WH)(P)}{L_H\ (C-1)}$$

Equations for Q, M, and B are relationships which quantify the effects of plant characteristics on water requirements. While these two equations allow the calculation of water requirements for a plant, it is possible to influence the cycles of concentration variable C, with certain conservation methods. These are discussed next.

c. Water Conservation Practices

Cooling system water conservation has one main goal -- reducing makeup requirements. Makeup replenishes evaporation and blowdown (or blowdown reclamation wastes). For wet, evaporative cooling towers, the evaporation requirement cannot be controlled. Therefore, any water conservation practice, regardless of its efficiency, still leaves a makeup requirement to satisfy evaporation.

There are two levels of water conservation through treatment that each site may practice to achieve a reduction in the blowdown or discharge requirements which, in turn, reduces makeup. These water treatment groups are:

- "Base level control" -- (Conventional or "privately optimal" technology) is defined as:
    1. Sulfuric acid addition for pH control;
    2. Automatic pH control equipment; and
    3. Automatic blowdown control.
- "Advanced control" -- includes available and proven treatment technology such as:
    1. Warm lime softening for hardness control;
    2. Polymer addition for scale control; and/or

3. Hydrochloric acid for pH control where sulfuric acid addition may promote calcium sulfate scaling.

"Advanced control" also embraces state-of-the-art technology such as brine concentration processes for blowdown control which include evaporators, reverse osmosis units, and demineralizers.

"Base level control" achieves a higher degree of water conservation than that produced by many plants. Typical power plant cooling tower systems are controlled between 1.5 and 3.0 cycles[1]. However, this practice cannot be tolerated in a water short area such as most of the Northern Great Plains. Therefore, "base level control" is defined as the minimum acceptable level of water conservation. Each site is expected to practice this level of control to approach the recirculation water quality limitations cited in Table II-A.1-2.

d. Water Requirements and Costs

Tables II-A.1-4 and II-A.1-5 list the cooling system water requirements and costs. Data shown in the Tables are the manifestation of the three factors that affect water requirements -- Makeup water quality, plant characteristics, and water conservation practices. Any contributions of acid addition costs to the total costs are based on early 1974 market prices of hydrochloric acid and sulfuric acid in bulk deliveries \$0.06/lb HCl and \$0.02/lb H_2SO_4. Where applicable, other costs are based on the data listed on Table II-A.1-6. The references cited provide further information on system efficiencies and physical descriptions.

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[1] Boies, Levin, and Baratz. Technical and Economic Evaluations of Cooling System Blowdown Control Techniques. Wapora, Inc., Washington, D.C. Report No. EPA-660/2-73-026. Environmental Protection Agency. 1974. 73 p.

TABLE II-A.1-4 COOLING SYSTEM WATER REQUIREMENTS AND COSTS - YELLOWSTONE RIVER SITES

Level of Control	Water Requirement m^3/MWH (acre-ft/yr)‡ Makeup	Blowdown	Total Cost Mills/KWH Fixed Charge Rate 0.12	Fixed Charge Rate 0.18
Base Level	1.972 (10900)	0.533 (3000)	0.0100	0.0100
Advanced Level				
HCl Addition	1.818 (10100)	0.379 (2100)	0.0298	0.0298
Polymer Addition	1.705 (9500)	0.266 (1500)	0.0130	0.0130
Lime Softening	1.503 (8300)	0.064* (350)	0.0204	0.0213
Brine Concentration**	1.439 (8000)	0*	0.2144	0.2904

*Discharge from treatment

**Cost data based on evaporators

‡ For a 1000 MW plant operating 6800 hours

TABLE II-A.1-5 COOLING SYSTEM WATER REQUIREMENTS AND COSTS - MISSOURI RIVER SITES

	Water Requirement m^3/MWH (acre-ft/yr) ‡		Total Cost Mills/KWH	
Level of Control	Makeup	Blowdown	Fixed Charge Rate 0.12	Fixed Charge Rate 0.18
Base Level	1.953 (11000)	0.514 (2800)	0.0094	0.0094
Advanced Level				
HCL Addition	1.818 (10100)	0.379 (2100)	0.0277	0.0277
Polymer Addition	1.727 (9600)	0.288 (1600)	0.0126	0.0126
Lime Softening	1.506 (8400)	0.067* (360)	0.0202	0.0212
Brine Concentration**	1.439 (8000)	0*	0.2276	0.3086

*Discharge from treatment

**Cost data based on evaporators

‡ For a 1000 MW plant operating 6800 hours

TABLE II-A.1-6 WATER CONSERVATION CONTROL SYSTEM COSTS

Control System	Capital Costs $\$/m^3/hr.$	O/M Costs $\$/10^3m^3$	References
Polymer addition to makeup	-	$\frac{4.4\text{-}31}{\text{cycles}}$	1, 2
Lime Softening	330	15	1, 3
Brine Concentration	38000	230	1, 4

1. Boies, Levin, and Baratz. Technical and Economic Evaluations of Cooling System Blowdown Control Techniques. Wapora, Inc., Washington, D.C. Report No. EPA-660/2-73-026. Environmental Protection Agency. 1974. 73 pages.

2. Schweitzer, G. W. How Phosphonates Control Scale and Corrosion in Cooling Water Systems. Heating/Piping/Air Conditioning. 43:78-82, May 1971.

3. Leung, P. and R. E. Moore. Water Consumption Study for the Navajo Plant. Presented at the 1971 ASCE National Meeting, Phoenix, AR. January 12, 1971.

4. Goldman, E. and Kelleher, P. Water Reuse in Fossil-Fueled Power Stations In Complete Water Reuse, Cecil, L. K. (Ed.) New York, N.Y. AICHE. April 1973. Pages 240-249.

II-A.2 Total Water Requirements

With the application of the 95 percent guideline for cooling water usage versus other uses, Tables II-A.1-4 and II-A.1-5 can be used to estimate the total water requirements of power plants on the Yellowstone and Missouri Rivers; the guideline applies to the cooling system makeup requirements corresponding to base level control.

Example -- Yellowstone River Plants, which practice base level control, have a cooling system makeup requirement of 1.972 m^3/MWH. The total intake flow rate is then,

$$1.972/0.95 = 2.075\ \mathrm{m^3/MWH}$$

The discharge flow rate is the sum of cooling tower blowdown and the secondary effluents, i.e.:

$$0.53 + (2.076 - 1.972) = 0.637\ \mathrm{m^3/MWH}$$

The above analytical procedure should not be interpreted as anything more than a rule-of-thumb estimation. There are at least two potential anomalies that can affect total water requirements; and thus make the guideline invalid.

The first anomaly is the use of SO_x scrubbers. The second is the application of water reuse programs.

a. SO_x Scrubbers

If scrubbers are employed, their water usage depends on the scrubbing process chosen (e.g. mag-ox, cat-ox, lime/limestone, double alkali). For this study the water requirements apply to lime/limestone scrubbing systems.

Makeup water is required to account for water losses due to: stack evaporation, sludge water entrainment, and leakages/discharges. For scrubber systems at both the Yellowstone and Missouri sites, the estimated water requirement is 0.481 m^3/MWH. This requirement is based on the following characteristics[1].

1. Stack gas

   Inlet temperature - 149°C (300°F)

   Outlet temperature - 49-54°C (120-130°F)

   Inlet humidity - 0%

   Flow rate - 50 m^3/hr/KW (3000 cfm MW)

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[1] Epstein, M., C. C. Leivo, C. H. Rowland, and S. C. Wang. Test Results from the EPA Lime/Limestone Scrubbing Test Facility. Bechtel Corporation, San Francisco, California. Presented at the Flue Gas Desulfurization Symposium. May 14-17, 1973. 100 p.

2. Sludge

Percent moisture 50%

Volume - twice the ash handling sludge volume

b. Water Reuse

Efficient water reuse, when applied on a plant-wide basis, reduces total water requirements. Examples of water reuse are:

1. Cooling system blowdown used as SO_2 scrubber makeup
2. Boiler blowdown recycled to boiler makeup (prior to boiler water treatment)
3. SO_x scrubber discharge used as ash sluicing water.

II-A.3 Summary

a. Cooling System Water Use/Conservation

Based on the technical and economic analyses, the Northern Great Plains power plants which require closed cycle operation have three available options (above base level control) in achieving cooling system water conservation:

1. Hydrochloric acid in place of sulfuric acid for pH control. While this option results in a 26% or more reduction in water requirements, its cost is almost three times that of base level control.

2. Polymer addition for scale control. This option shows promise. It has the potential of reducing water requirements by about 45%; at the same time it increases water treatment costs by only 26-30%. On the other hand, it requires the proper selection of both chemicals and water treatment consultants to insure operational reliability and good service and acceptable effluents.

3. Warm lime softening for scale control. This final option can reduce water requirements by 87% and more because the softener effluent can be reused as a portion of the cooling system makeup. Its cost is 113% more than base level control. Furthermore, the process can facilitate "zero discharge" if the softener sludge can be sent to the ash handling system. However, it does require (a) considerable capital investment, (b) significant chemical usage and (c) the attention of an operator or maintenance man to assure smooth operation.

Blowdown brine concentration is a "near future" water conservation method. The practical potential of this method is yet to be demonstrated on large cooling systems. Therefore, the brine concentration cost data are close approximations at best; they are presented herein for comparative purposes only.

Tables II-A.3-1 and II-A.3-2 quantify the water conservation achievable by the above methods. The water flow rates shown are based on a 1000 MWe power plant operating with a 0.77 average annual capacity factor.

b. Total Plant Water Use/Conservation

Unlike the cooling system requirements, total power plant water usage can only be estimated at this time. Tables II-A.3-3 and II-A.3-4 contain the range of water requirements for plants with and without SO_x scrubbers. The range of values reflect the degree of water reuse employed. In each column the higher value assumes minimum water reuse, the lower value assumes maximum water reuse. Other plant conditions on which the water usage is based are:

TABLE II-A.3-1 COOLING SYSTEM WATER REQUIREMENT REDUCTIONS - YELLOWSTONE RIVER PLANTS

	Water Flow Rates* m^3/hr		% Reduction of makeup (over Base Level Control)	% Reduction of blowdown (over Base Level Control)
Water Conservation Method	Makeup	Blowdown		
Base Level Control	1518	410	-	-
HCl Addition	1400	292	8	29
Polymer Addition	1312	205	14	50
Blowdown Lime Softening	1157	49**	24	88
Blowdown Brine Concentration	1108	0**	27	100

* 1000 MWe plant - 0.77 ave. annual capacity factor

** Discharge from treatment

TABLE II-A.3-2 COOLING SYSTEM WATER REQUIREMENT REDUCTIONS - MISSOURI RIVER PLANTS

	Water Flow Rates* m^3/hr.		% Reduction of makeup (over Base Level Control)	% Reduction of blowdown (over Base Level Control)
Water Conservation Method	Makeup	Blowdown		
Base Level Control	1503	396	-	-
HCl Addition	1400	292	7	26
Polymer Addition	1330	222	12	44
Blowdown Lime Softening	1160	52**	24	87
Blowdown Brine Concentration	1108	0**	26	100

* 1000 MWe plant - 0.77 ave. annual capacity factor

** Discharge from treatment

TABLE II-A.3-3 TOTAL PLANT WATER REQUIREMENTS - YELLOWSTONE RIVER SITES*

Level of Cooling System Control	with SO_x Scrubbers		without SO_x Scrubbers	
	Intake Requirement m^3/MWH (acre-ft/yr) **	Discharge Requirement m^3/MWH (acre-ft/yr) **	Intake Requirement m^3/MWH (acre-ft/yr) **	Discharge Requirement m^3/MWH (acre-ft/yr) **
Base Level Control	1.979-2.557 (10900-14200)	0-0.637 (3500)	1.972-2.076 (10900-11500)	0.474-0.637 (2600-3500)
Advanced Control				
HCL Addition	1.979-2.403 (13300)	0-0.483 (2700)	1.818-1.922 (10100-10600)	0.320-0.483 (1800-2700)
Polymer Addition	1.979-2.290 (12700)	0-0.370 (2040)	1.705-1.809 (9500-10000)	0.207-0.370 (1150-2050)
Blowdown Lime Softening	1.979-2.088 (11500)	0-0.168 (930)	1.503-1.607 (8300-8900)	0.005-0.168 (30-930)
Blowdown Brine Concentration	1.979-2.024 (11200)	0-0.104 (570)	1.498-1.543 (8000-8500)	0 -0.104 (0-580)

*In all columns: low number reflects maximum water reuse; high number reflects minimum water reuse.

**Assumes 6800 hrs of operation for a 1000 MW plant.

TABLE II-A.4-4 TOTAL PLANT WATER REQUIREMENTS - MISSOURI RIVER SITES*

Level of Cooling System Control	With SO_x Scrubbers Intake Requirement m^3/MWH (acre-ft/yr) **	With SO_x Scrubbers Discharge Requirement m^3/MWH (acre-ft/yr) **	Without SO_x Scrubbers Intake Requirement m^3/MWH (acre-ft/yr) **	Without SO_x Scrubbers Discharge Requirement m^3/MWH (acre-ft/yr) **
Base Level Control	1.979-2.537 (10900-14100)	0-0.607 (3400)	1.953-2.056 (10800-11400)	0.455-0.607 (2500-3400)
Advanced Control				
HCl Addition	1.979-2.402 (13300)	0-0.482 (2700)	1.818-1.921 (10400-10600)	0-320-0.482 (1800-2700)
Polymer Addition	1.979-2.311 (12800)	0-0.391 (2200)	1.727-1.830 (9600-10200)	0-299-0.391 (1700-2200)
Blowdown Lime Softening	1.972-2.090 (11600)	0-0.170 (950)	1.506-1.609 (8400-8900)	0.008-0.170 (45-950)
Blowdown Brine Concentration	1.979-2.023 (11200)	0-0.103 (570)	1.498-1.542 (8000-8600)	0 -0.103 (0-570)

* In all columns: low number reflects maximum water reuse; high number reflects minimum water reuse.

** Assumes hrs of operation for a 1000 MW plant.

1. Tower drift rate - 0.005% of recirculating rate;
2. Onsite evaporation/precipitation - negligible net effect;
3. Fly ash and bottom ash water entrainment - 50% by weight;
4. Boiler system losses - 0.5% of steam rate.

For power plants without SO_x scrubbers, the higher intake and discharge requirements (corresponding to minimum water reuse) are based on the 95% guideline. The lower intake and discharge requirements (corresponding to maximum water reuse) consider the total estimated water consumption in the plant; therefore, the discharge requirement is the cooling tower blowdown requirement minus the water consumed by cooling tower drift, ash entrainment and boiler system losses.

The same logic applies to power plants with SO_x scrubbers. The higher intake requirements are based on the 95% guideline plus the estimated scrubber water consumption. The higher discharge requirements are the same as the corresponding higher discharge requirements of plants without scrubbers; because the scrubber water usage is based on no water loss or discharge other than stack evaporation and sludge entrainment. The lower intake and discharge requirements consider the total estimated water consumption -- including the scrubber requirements.

Each plant has an irreducible minimum intake requirement. Furthermore, it is essentially independent of water conservation/reuse techniques -- regardless of the effectiveness of the techniques. This minimum is approached as the plant approaches a zero discharge. For all plants along the Missouri and Yellowstone, the estimated irreducible minimum intake requirements are,

For plants with SO_x scrubbers - 1.979 m^3/MWH (10,900 acre-ft/yr) *

For plants without SO_x scrubbers - 1.498 m^3/MWH (8000 acre-ft/yr) *

* For 6800 hr per year operation of a 1000 MW plant; recirculating water cooled.

II-B Engineering and Economic Aspects of Wet and Dry Cooling Systems[1]

This section presents an evaluation of the engineering and economic aspects of cooling water systems for 1000 megawatt coal fired power plants at three sites within the Northern Great Plains study area (Colstrip, Montana; Gillette, Wyoming; Stanton, North Dakota). Closed-cycle cooling systems with wet and dry mechanical draft cooling towers are selected for analysis. In addition, once-through cooling is evaluated for economic comparison. System design is based upon design meteorological conditions representative of critical summer months. Annual operating characteristics and costs are evaluated using long-term seasonal average weather conditions.

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[1] After paper prepared by Bruce A. Tichenor and Mastafa A. Shirazi of the Northwestern Environmental Research Center, EPA, Corvallis, Oregon.

II-B.1 Meteorology

The design and operation of facilities to dissipate waste heat from thermal power plants are dependent to a large degree upon the weather. Therefore, accurate meteorological data are required. Both design and off-design (i.e., annual variations) data must be compiled.

The meteorological variables of significance for this study include:

For wet towers: wet and dry bulb air temperatures;

For dry towers: dry bulb temperatures (frequency distribution);

For once-through: water temperatures.

Data on wet and dry-bulb temperatures are contained in Table II-B.1-1. The design data provided are for temperatures not exceeded more than 5 percent of the time during the summer months. These data were obtained from a compilation of power plant environmental impact statements and weather bureau records[1]. Note that average values for Colstrip and Gillette are provided.

Tables II-B.1-2, II-B.1-3 and II-B.1-4 contain an analysis of the annual frequency distribution of dry bulb temperatures for Bismarck, North Dakota (applied to Stanton), Sheridan, Wyoming (applied to Gillette), and Miles City, Montana (applied to Colstrip). The data in Table II-B.1-2 were obtained from an EPA report by R. W. Beck[2], while Tables II-B.1-3 and II-B.1-4 were developed from information received from Young[3].

It was assumed that any surface water which would be available to a power plant would be from a completely mixed water body at equilibrium temperature (i.e., the temperature at which the net exchange of energy across the air-water interface is zero). Data on equilibrium temperatures[4] were examined for Casper, Wyoming;

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1. Shaw, J., Unpublished communication on meteorology, water quality, and power plant economic and operating data. EPA, Region VIII, January, 1974.
2. R. W. Beck and Associates, Research on dry-type cooling towers for thermal electric generation, Part I, U.S. EPA, Water Pollution Control Research Series No. 16130 EES11/70, November, 1970.
3. Young, R., Personal communication (unpublished), R. W. Beck Associates, February, 1974.
4. Vanderbilt University, Effect of geographical location on cooling and pond requirements and performance, U.S. EPA Water Pollution Control Research Series No. 16130 FDQ3/71, March, 1971.

TABLE II-B.1-1

Wet and Dry Bulb Air Temperatures

	Wet Bulb					Dry Bulb				
Location	Design	Winter	Spring	Summer	Fall	Design	Winter	Spring	Summer	Fall
Colstrip, MT	70.0	22.0	38.9	58.4	42.3	90.0	24.3	44.1	68.9	47.6
Gillette, WY	70.0	21.9	37.0	57.6	41.8	90.0	24.3	42.4	67.9	47.5
Average*	70.0	21.9	38.0	58.0	42.0	90.0	24.3	43.2	68.4	47.5
Stanton, N.D.	70.6	11.9	35.8	59.7	38.7	88.0	14.5	40.7	67.4	44.2

Winter - December, January, February
Spring - March, April, May
Summer - June, July, August
Fall - September, October, November

* Colstrip and Gillette

TABLE II-B.1-2 - Annual Distribution of Air Temperature for Bismarck, North Dakota (Used for Stanton)

Air Temperature Range (°F)	Percent of Time	Air Temperature Range (°F)	Percent of Time
119/115	0	39/ 35	6.89
114/110	0	34/ 30	7.45
109/105	0.01	29/ 25	6.27
104/100	0.07	24/ 20	5.40
99/ 95	0.32	19/ 15	4.23
94/ 90	0.89	14/ 10	3.85
89/ 85	1.72	9/ 5	3.33
84/ 80	2.87	4/ 0	3.17
79/ 75	4.07	- 1/- 5	2.37
74/ 70	5.18	- 6/-10	1.49
69/ 65	6.46	-11/-15	0.88
64/ 60	7.00	-16/-20	0.54
59/ 55	6.91	-21/-25	0.23
54/ 50	6.42	-26/-30	0.10
49/ 45	5.93	-31/-35	0.03
44/ 40	5.91	-36/-40	0.01

TABLE II-B.1-3 - Annual Distribution of Air Temperature for Sheridan, Wyoming (Used for Gillette)

Air Temperature Range (°F)	Percent of Time	Air Temperature Range (°F)	Percent of Time
119/115	0	39/ 35	8.90
114/110	0	34/ 30	8.20
109/105	0	29/ 25	5.99
104/100	.05	24/ 20	4.29
99/ 95	.44	19/ 15	3.12
94/ 90	1.13	14/ 10	2.69
89/ 85	1.99	9/ 5	2.53
84/ 80	2.88	4/ 0	1.31
79/ 75	4.06	- 1/- 5	.29
74/ 70	5.23	- 6/-10	.25
69/ 65	6.16	-11/-15	.10
64/ 60	7.30	-16/-20	.10
59/ 55	8.15	-21/-25	0
54/ 50	8.24	-26/-30	0
49/ 45	8.12	-31/-35	0
44/ 40	8.48	-36/-40	0

TABLE II-B.1-4 - Annual Distribution of Air Temperature for Miles City, Montana (Used for Colstrip)

Air Temperature Range (°F)	Percent of Time	Air Temperature Range (°F)	Percent of Time
119/115	0	39/ 35	7.68
114/110	0	34/ 30	7.11
109/105	.05	29/ 25	5.62
104/100	.30	24/ 20	4.12
99/ 95	.91	19/ 15	3.39
94/ 90	1.68	14/ 10	3.34
89/ 85	2.60	9/ 5	3.52
84/ 80	3.68	4/ 0	2.12
79/ 75	4.60	- 1/- 5	.60
74/ 70	5.70	- 6/-10	.60
69/ 65	6.71	-11/-15	.20
64/ 60	7.24	-16/-20	.19
59/ 55	7.10	-21/-25	0
54/ 50	6.90	-26/-30	0
49/ 45	6.78	-31/-35	0
44/ 40	7.30	-36/-40	0

Billings, Montana; and Bismarck, North Dakota. The data for these three locations were essentially the same for both design (summer extreme) and average conditions. Thus, the following values of temperature were used for available water at all three sites:

Design - 79°F;
Winter - 32°F;
Spring - 49°F;
Summer - 75°F;
Fall - 49°F.

II-B.2 Economic Considerations

The cost of power generation, called the "busbar cost", is expressed in Mills/KHW and is usually broken down into fixed and variable cost components. Fixed charges are those which are unaffected by plant output and include interest on money, amortization of the plant capital cost, interim replacements, insurance, and taxes. The annual fixed charge rate is expressed as a percentage of plant capital cost. It is the sum of the charges allotted to each contributing item noted above. In determining the fixed cost contribution to total busbar cost, the annual cost is calculated in dollars and then converted to Mills/KWH in accordance with plant operation time.

Variable costs, also called operating costs or production costs, are those associated with the amount of generation and include fuel, payroll labor, and other operating and maintenance expenses. Each of these items is expressed in terms of Mills/KHW.

Both fixed and variable costs are influenced by the heat dissipation system of a plant. The opposite is also true, because general cost factors play a major roll in the optimal design of a plant-cooling system combination. Hence, it is important to establish economic criteria in the early stages of any study of this type.

Data on plant capital costs, fuel costs, and fixed charge rates for power plants that might be constructed in the Northern Great Plains Study were provided[1]. Table II-B.2-1 gives the low, high, and, if appropriate, medium values for these cost factors. In the economic analysis which follows, several combinations of these cost factors are examined.

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[1] Shaw, J., Unpublished communication on meteorology, water quality, and power plant economic and operating data. EPA, Region VIII, January, 1974.

TABLE II-B.2-1

Cost Factors

Magnitude	Plant Capital Cost ($/KW)	Fixed Charge Rate (%)	Fuel Cost (¢/10^6 BTU)
Low	300	12	16
Medium	---	15	--
High	400	18	19

II-B.3 Engineering Considerations

The initial requirements for approximating the size and performance of alternative cooling systems are the meteorological and economic data given previously. Based on these data and generalized cost estimates for system components and operation, component sizes and performance characteristics are determined via digital computer programs.

The procedure for designing each cooling device varied according to the source of the computer programs. A computer program developed by the Dynatech Corporation was used as a primary means for analyzing wet cooling towers and once-through systems[1]. Design and cost data on mechanical draft dry (Heller) cooling systems were obtained from the analysis provided by R. W. Beck and Associates[2].

The Dynatech and R. W. Beck computer programs are the results of EPA research contract efforts. Supplementary cost data on wet towers were obtained from The Marley Company[3] and Kolflat[4]. Cross-referencing and spot checks between Dynatech, R. W. Beck and in-house calculations were made to assure consistency and reasonable agreement of the results despite the varied approaches used in system design.

Detailed discussions of the optimization procedures used are not given here. The interested reader is urged to consult the original sources(1, 2) for such details. In addition, a report on alternative cooling systems for the Lake Michigan area[5] contains information on the procedures, as well as numerical results.

The two computer programs used in this study have substantially different input requirements. In order to properly evaluate the final results of the analyses, input data are provided for review. It should be noted that both programs contain coefficients, constants, and other inputs which can be changed by the user. Unless noted, the program constants used in this study are as contained in the source references.

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1. Dynatech R/D Company, A survey of alternate methods for cooling condenser discharge water-system selection, design, and optimization, U.S. EPA, Water Pollution Control Research Series No. 16130 DHS01/71, January, 1971.
2. R. W. Beck and Associates, Research on dry-type cooling towers for thermal electric generation, Part I, U.S. EPA, Water Pollution Control Research Series No. 16130 EES11/70, November, 1970.
3. Dickey, J. D., Jr. and R. E. Cates, Managing waste heat with the water cooling tower, 2nd Edition, The Marley Company, Mission, Kansas, April, 1973.
4. Kolflat, T. D., Cooling tower practices, Power Engineering, January, 1974, pp. 32-39.
5. FWPCA, Feasibility of alternative means of cooling for thermal power plants near Lake Michigan, National Thermal Pollution Research Program, Corvallis, Oregon and Great Lakes Regional Office, Chicago, Illinois, September, 1970.

In addition to the meteorological and economic data given previously, the Dynatech program requires input data on plant capacity on an annual cycle and turbine heat rate.

An average annual plant capacity factor of 0.77 was selected, based on information provided by EPA Region VIII[1]. The following distribution of load on the 1000 MWe base plant was selected to correspond to the 0.77 plant capacity factor:

						Total
Capacity	1.0	0.8	0.6	0.4	0	--
Hours/yr	4000	2000	1310	900	660	8760

In order to evaluate the operation of the cooling system throughout the annual cycle, the Dynatech program requires a seasonal distribution of plant capacity; Table II-B.3-1 provides the calculation.

Another important system cost factor is the turbine heat rate and its variation with capacity factor and the condenser operating temperature. Data for typical GE turbine of a 1000 MWe capacity were used with the Dynatech program. Turbine heat rates at several capacity factors were obtained from the manufacturer's heat rate tables[2]. Table II-B.3-2 repeats these data. (Note that these are heat rates for a specific turbine and should not be equated to an overall plant heat rate.)

The Dynatech program contains cost functions for all components of the cooling system, including condenser, pumps, cooling tower, intake and outlet structures, etc. A review of recent literature(3, 4, 5) and manufacturer's data was undertaken to update these cost functions. This review indicated that the cost functions contained in the Dynatech program were still generally applicable. Two changes were made. Condenser costs were increased by 50 percent to account for recent increases in cost. The overall heat transfer coefficient for the condenser was assumed to be 525 BTU/hr-ft^3 - ^{o}F. Also, pump costs were increased from \$1/gpm to \$1.70/gpm[5]. These changes in cost functions cause relatively minor increases in cooling system cost over the original Dynatech values.

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1. Shaw, J., Unpublished communication on meteorology, water quality, and power plant economic and operating data. EPA, Region VIII, January, 1974.
2. Western Gasification Company, Federal Power Commission filing; Docket No. CP-73-211; February 21, 1973.
3. Dickey, J. B., Jr. and R. E. Cates, Managing waste heat with the water cooling tower, 2nd Edition, The Marley Company, Mission, Kansas, April, 1973.
4. Kolflat, T. D., Cooling tower practices, Power Engineering, January, 1974, pp. 32-39.
5. Jedlicka, C. L., Nomographs for thermal pollution control systems, U.S. EPA, Environmental Protection Technology Series, EPA-660/2-73-004, September, 1973.

TABLE II-B.3-1

Percent of Time at Various Capacities on a Seasonal Basis

Plant Capacity	Winter	Spring	Summer	Fall
1.0	30	20	30	20
0.8	25	25	25	25
0.6	25	25	25	25
0.4	18	32	18	32
0	0	50	0	50

TABLE II-B.3-2

Turbine Heat Rates* (BTU/KWH)

	Back Pressure (in. Hg)			
Capacity	1.0	2.0	3.0	3.5
1.0	7415	7532	7716	7805
0.8	7483	7659	7855	7941
0.6	7674	7947	8181	8283
0.4	8045	8434	8728	8847

*For a 1000 MWe turbine, cross-compound, 3600/1800 RPM, 3500 PSIG, 1000/1000F, 6 flow, 38 inch last stage blades.

	1	2	3	4	5
VWO	7397	7532	7732	7921	8093
100	7386	7533	7732		
75	7439	7673	7902	8097	8268
50	7739	8091	8372	8602	8793

The R. W. Beck program was written for optimizing Heller-type mechanical and natural draft dry tower cooling systems for steam electric power generating plants. The dry tower system is "optimized" with respect to four major cost items: capital cost, auxiliary power cost, plant fuel cost, and cost of replacing lost capacity. The program does not provide an exact cost optimization of a dry cooling tower system at this time because of two major problems: a) unavailability of performance and cost data for high back pressure turbines and b) the proprietary nature of information on cost and performance of cooling coils. Reasonable extrapolations based on the current turbine designs and order of magnitude estimates of prepackaged cooling coil-fan modules are used in the program. The cost information provided by R. W. Beck[1] has not been increased due to inflation since 1969.

The R. W. Beck program was run for both summer and winter peaking. In the summer peaking mode, the program provides gas turbine peaking units ($100/KW, 40¢/$10^6$ BTU fuel cost, 15,000 BTU/KWH heat rate, and $1.20/KW O&M cost) to make up lost capacity during the summer when excessively high air temperatures occur more than ten hours per year. Since most of the power to be generated in the Northern Great Plains will be exported, summer peaking capacity could be provided by the end user (e.g., a Chicago utility) instead of at the site (e.g., Colstrip). Thus, a winter peaking season, where the advantages of cool temperatures provide low power plant heat rates, was also analyzed. For winter peaking, gas turbines are not required.

For both summer and winter peaking, the plant provides 6.56 x 10^6 MWH of electric power. This is based on an average annual plant capacity of 0.75 with the following distribution:

Capacity	1.0	0.75	0
Hours/yr	3750	3750	1260

In order to obtain equivalent power output under both summer and winter peaks, the cost data provided are not truly "optimal", because the data were selected at the specific initial temperature difference which gave the desired plant output rather than the "optimal" initial temperature difference.

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[1] R. W. Beck and Associates, Research on dry-type cooling towers for thermal electric generation, Part I, U.S. EPA, Water Pollution Control Research Series No. 16130 EES11/70, November, 1970.

II-B.4 Results

Economic data for the three cooling systems analyzed (i.e., once-through, closed-cycle wet mechanical draft cooling towers, and Heller type dry towers[1]) are presented in tabular form. For once-through and wet towers, the Gillette and Colstrip sites were run as one site, since the relevant meteorological parameters were essentially equal. As stated previously, the Dynatech and R. W. Beck programs were run for several combinations of the economic factors contained in Table II-B.2-1.

Only minor variations in wet cooling system design characteristics occurred between the various cases analyzed. For once-through cooling systems, the condenser Δ T varied from a low of 26°F to a high of 31°F with an average of 28°F[2]. For the wet mechanical draft tower, the cooling range averaged 26°F and the approach temperature was 19°F[2].

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1. In the Heller design condensate circulates through air fin coolers and steam is condensed by condensate injection into a special vessel.

2. Wet Cooling Towers, both mechanical and natural draft, dissipate the majority (approximately 75%) of the waste heat in the cooling water by latent heat transfer (evaporation) with the remainder lost by sensible heat transfer (conduction-convection). The wet-bulb temperature of the ambient air is the minimum temperature to which the water can be cooled. The tower is designed to cool the water to some specified temperature above the wet-bulb temperature.

   The approach of the tower is defined as the difference between the cool outlet water and the wet-bulb temperature. Approaches of 15-20°F are generally used. The cooling range is the difference between the hot inlet water temperature and the cool outlet water temperature. In a closed-cycle system, the range equals the condenser temperature rise and is generally between 25 and 40°F. Thus, given information on the approach, range, and wet-bulb temperature, one can determine the inlet (hot leg) and outlet (cold leg) tower temperatures. For a given range, the lower the approach the larger and more expensive the tower, but the cooler the water and the more efficient the power plant. Thus, an optimal approach must be determined by balancing capital and operating expenditures.

   In evaluating tower performance, one must differentiate between design conditions and average conditions. Design wet-bulb temperature is often designated as not to be exceeded more than a fixed percentage (say 5%) of the time during the summer months. It represents a severe condition. Average conditions will be much more moderate. For example, a particular tower may be designed for a 15°F approach, a 30°F range, and 75°F wet-bulb temperature. This would provide a 120°F tower inlet temperature with a 90°F outlet temperature. Under more moderate weather conditions much cooler temperatures will be realized.

The cost data for once-through and closed-cycle wet towers are contained in Table II-B.4-1. The data for all three sites were averaged, since the slight variation in meteorology did not cause significant differences in cost. The last column in this table shows the overall economic impact of the cooling system on the total busbar cost. It includes fixed charges, O&M costs, and fuel penalties.

Table II-B.4-2 provides cost data for dry (Heller type) towers for the three sites. Note that the capital cost of the tower at each site was constant. The three columns in Table II-B.4-2 for each site provide the following information:

> Total plant fuel cost - The average annual fuel cost, including the cost of fuel to run the auxiliary equipment for the cooling systems, but excluding the fuel used in gas turbine peaking units. For the conditions examined in this report, the auxiliary energy required is 1 to 2 percent of the total plant energy generated. This information is reflected in the annual plant fuel cost.
>
> Total system cost - The average annual cost for the cooling system, including fixed charges, O&M, and peaking costs, plus the total plant fuel cost.
>
> Cooling system penalty - The difference between the first two columns; this column provides the total cost attributable to the cooling system, exclusive of fuel penalties for auxiliaries. As is noted below, this column cannot be directly compared with the last column in Table II-B.4-1.

The initial temperature difference[1] values used in the dry tower analyses are: Colstrip, 61.3°F; Gillette, 63.5°F; Stanton, 64.5°F.

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[1] The primary design variable for dry towers is the Initial Temperature Difference (ITD), which is the difference between the incoming hot water and the ambient air dry-bulb temperature. The selection of the ITD requires an evaluation of four major cost items--capital cost, auxiliary power cost, cost to the loss of capacity, and fuel cost. At large ITD's the cooling system is highly efficient and thus compact and relatively inexpensive. The auxiliary power requirements are also relatively small. On the other hand, the loss of power plant capability and the increased fuel cost due to lower power plant efficiencies caused by high cooling water temperatures are large. Thus, the capital cost and auxiliary power cost are low at high ITD's while the cost due to the loss of capacity and fuel costs are low at low ITD's. The optimal ITD for a given region is consequently dictated by the combined effects of all four cost factors. In studies conducted to evaluate dry cooling towers for thermal power plants in the Northern Great Plains, design ITD values of 60-65°F were used.

TABLE II-B.4-1

Cost of Wet Cooling Systems

Plant Capital Cost ($/KW)	Fuel Cost (¢/10^6 BTU)	Fixed Charge Rate (%)	Type of Cooling System *	Capital Cost ($/KW) Condenser and Pumps	Capital Cost ($/KW) Cooling Device **	Total Cooling System Cost *** (Mills/KW hr)
300	16	15	OT	4.81	1.25	0.155
			MD	5.13	2.37	0.226
300	16	12	OT	4.97	1.25	0.128
			MD	5.13	2.37	0.182
300	16	18	OT	4.60	1.25	0.180
			MD	5.15	2.37	0.270
300	19	15	OT	4.88	1.25	0.157
			MD	5.13	2.37	0.226
400	19	15	OT	4.81	1.25	0.162
			MD	5.18	2.32	0.244
400	16	15	OT	4.73	1.25	0.160
			MD	5.18	2.32	0.243
400	19	18	OT	4.66	1.25	0.189
			MD	5.13	2.37	0.291

* OT = once-through; MD = closed-cycle, wet mechanical draft towers

** For once-through systems, this cost covers intake and outlet structures

*** Average annual cost

TABLE II-B.4-2

Cost Data for Mechanical Draft Dry Cooling Systems

Peaking Season	Plant Capital Cost ($/KW)	Fixed Charge Rate (%)	Fuel Cost (¢/10^6 BTU)	Colstrip Tower Capital Cost = $16.5/KW			Gillette Tower Capital Cost = $16.0/KW			Stanton Tower Capital Cost = $15.4/KW		
				Total Plant Fuel Cost * (Mills/KWH)	Total System Cost ** (Mills/KWH)	Cooling System Penalty (Mills/KWH)	Total Plant Fuel Cost * (Mills/KWH)	Total System Cost ** (Mills/KWH)	Cooling System Penalty (Mills/KWH)	Total Plant Fuel Cost * (Mills/KWH)	Total System Cost ** (Mills/KWH)	Cooling System Penalty (Mills/KWH)
Summer	300	12	16	1.488	2.184	.696	1.488	2.149	.661	1.483	2.132	.649
			19	1.767	2.463	.696	1.767	2.428	.661	1.761	2.410	.649
		18	16	1.488	2.494	1.006	1.488	2.445	.957	1.483	2.421	.938
			19	1.767	2.773	1.006	1.767	2.724	.957	1.761	2.699	.938
	400	12	16	1.488	2.222	.734	1.488	2.186	.698	1.483	2.167	.684
			19	1.767	2.501	.734	1.767	2.465	.698	1.761	2.445	.684
		18	16	1.488	2.551	1.063	1.488	2.499	1.011	1.483	2.474	.991
			19	1.767	2.830	1.063	1.767	2.778	1.011	1.761	2.752	.991
Winter	300	12	16	1.493	1.938	.445	1.493	1.923	.430	1.493	1.905	.412
			19	1.773	2.218	.445	1.773	2.203	.430	1.773	2.185	.412
		18	16	1.493	2.149	.656	1.493	2.124	.631	1.493	2.098	.605
			19	1.773	2.429	.656	1.773	2.404	.631	1.773	2.378	.605
	400	12	16	1.493	1.979	.485	1.493	1.959	.466	1.493	1.940	.447
			19	1.773	2.259	.486	1.773	2.239	.466	1.773	2.220	.447
		18	16	1.493	2.202	.709	1.493	2.178	.685	1.493	2.152	.659
			19	1.773	2.482	.709	1.773	2.458	.685	1.773	2.432	.659

* Exclusive of peaking fuel cost

** Includes total plant fuel cost, including peaking costs

II-B.5 Summary and Conclusions

The different methods of optimization used by the two programs make it difficult to make a direct comparison between the two outputs. For example, the Dynatech program directly provides the total cost penalty associated with the cooling system (i.e., the last column in Table II-B.4-1), while the R. W. Beck program computes cooling system cost including plant fuel cost. In order to provide a direct comparison of costs between wet and dry tower systems, it was necessary to determine the total plant fuel cost for the wet systems and add it to the cooling system cost, thus providing a total system cost comparable to total system cost column in Table II-B.4-2 for dry towers. Using a nominal plant heat rate of 9000 BTU/KWH, plant fuel costs of 1.44 Mills/KWH for 16¢/10^6 BTU coal and 1.71 Mills/KWH for 19¢/10^6 BTU coal were obtained. These values were added to the last column in Table II-B.4-1 to obtain total system cost. Table II-B.4-1 contains total system cost information for each of the three cooling systems for several combinations of cost factors (Table II-B.2-1) and thus provides a direct measure of comparison between the systems.

A large number of cost comparisons can be made using Table II-B.5-1. Once-through vs. wet mechanical draft, once-through vs. dry mechanical draft (at each of the three sites), and wet mechanical draft vs. dry mechanical draft (at each of the three sites). These comparisons are made simply by obtaining the difference between the relevant total system cost values. For example, the difference in cost between wet and dry mechanical draft towers for Gillette given a $300/KW plant cost, 12 percent fixed charge rate, 16¢/10^6 BTU fuel cost, and assuming a summer peaking season, is (2.15 Mills/KWH minus 1.62 Mills/KWH) 0.53 Mills/KWH. This value represents the difference in total busbar cost due to the selection of a dry tower over a wet tower.

Table II-B.5-2 provides several comparisons for the Gillette site using data obtained from Table II-B.5-1. It is important to recognize that the data in Table II-B.5-2 represent the internalized economic consequence (expressed in additional busbar cost) of selecting one type of cooling system over another.

This chapter admittedly contains a large amount of data, some of it in a form not amenable to simple evaluation. Hopefully, the data contained in the tables, especially Tables II-B.5-1 and II-B.5-2, are described with enough clarity to allow a reasoned judgment concerning the costs of power plant cooling systems in the Northern Great Plains Study Area. With that hope in mind, no attempt will be made here to list all of the conclusions which can be extracted from the data. However, three general conclusions do bear mentioning:

1. For both wet and dry systems, the variation in fixed charge rate has a much greater effect on cooling system cost than the variations in either fuel cost or plant capital cost.

TABLE II-B.5-1

Summary of Cooling System Cost
(Cost of Water Not Included)

				Total System Cost* (Mills/KWH)				
						Dry MD		
Peaking Season	Plant Capital Cost ($/KW)	Fixed Charge Rate(%)	Fuel Cost (¢/10^6BTU)	Cnce-Through	Wet MD	Colstrip	Gillette	Stanton
Summer	300	12	16	1.57	1.62	2.18	2.15	2.13
Summer	300	18	16	1.62	1.71	2.49	2.45	2.42
Summer	400	18	19	1.90	2.00	2.83	2.78	2.75
Winter	300	12	16	1.57	1.62	1.94	1.92	1.91
Winter	300	18	16	1.62	1.71	2.15	2.12	2.10
Winter	400	18	19	1.90	2.00	2.48	2.46	2.43

*Cost of cooling system plus plant fuel cost.

TABLE 11-B.5-2

Cooling System Cost Comparison for Gillette

				Cost Differential*(Mills/KWH)			
Peaking Season	Plant Capital Cost ($/KW)	Fixed Charge Rate (%)	Fuel Cost (¢/10^6BTU)	Once-through vs Wet MD	Once-through vs Dry MD	Wet MD** vs Dry MD	Wet MD*** vs Dry MD
Summer	300	12	16	0.05	0.58	0.53	.05
Summer	300	18	16	0.09	0.83	0.74	.26
Summer	400	18	19	0.10	0.88	0.78	.30
Winter	300	12	16	0.05	0.35	0.30	-.18
Winter	300	18	16	0.09	0.50	0.41	-.07
Winter	400	18	19	0.10	0.56	0.46	-.02

*The cost differentials represent the higher busbar cost which would result from the selection of the more expensive of the two competing systems.

**Water costs not included.

***Water costs included at $300/acre ft.

Negative values denote lower costs for dry cooling.

2. Providing for winter peaking rather than summer peaking substantially reduces the cost of dry towers.

3. A direct comparison of wet mechanical draft vs. dry mechanical draft costs requires the cost of water (if significant) to be evaluated. Chapter II indicates that 1.97 M^3/MWH of make-up water is required for a wet mechanical draft system using base level water conservation control. Using this value along with a range of water costs of \$100 to \$300/ac-ft., water cost of 0.16 to 0.48 Mills/KWH are obtained. Adding these values to the cost of wet mechanical draft systems (Table II-B.5-1) shows that at the higher water costs and for winter peaking, dry mechanical draft systems become economically attractive and indeed may be less expensive than wet mechanical draft systems.

II-C Water Usage in the Conversion of Coal to Pipeline Quality Gas[1]

Although techniques for the manufacture of low-BTU gas from coal are well-established, technology for upgrading the fuel gas to the quality of pipeline gas is in the early stages of development. As such, many questions regarding the resource requirements for a plant producing substitute natural gas are unanswered. Nonetheless, proper planning for resource utilization will require good estimates of the demands such an installation will place on the environment.

The two major resources required for a coal gasification industry are, of course, coal and water. Requirements for the former may be estimated with a fair degree of accuracy given the chemical composition and heat value of the coal and the projected plant size. Quantification of the water demand, however, involves more variables, several of which revolve around technology yet to be developed. Nevertheless estimates of anticipated water usage have been made by process developers and plant designers. Of the several potential pressure gasification processes under various sponsorship, only that licensed by Lurgi Mineraloltechnik has attained the design state for commercial application. As such, the Lurgi serves a base with which to estimate the requirements for water and the potential changes in those requirements.

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[1] After a paper by James P. Chasse of the Northwest Environmental Research Center, EPA, Corvallis, Oregon.

II-C.1 Lurgi Process

The Lurgi Process developed in Germany is employed at a number of plants in other countries for the production of low or intermediate-BTU fuel gas. With the application of new technology, this product gas may be methanated to pipeline quality. Chemical reactions and process train components are essentially the same as for those processes under development.

A schematic of the Lurgi Process is shown in Figure II-C.1-1. Crushed coal is sized and fed into a lock hopper and then into a gasifier section which operates at approximately 450 psi. The reactions in the gasifier are such that the coal, moving down through the gasifier, is successively dried, devolatilized, gasified, and partially burned in the presence of steam and oxygen introduced at the bottom of the gasifier.

The drying and devolatilization result from direct contact with hot gases leaving the gasification zone. Carbon is gasified by the reaction:

$$C + H_2O + \text{heat} = CO + H_2$$

Hydrogen is also produced by the reaction:

$$CO + H_2O = CO_2 + H_2 + \text{heat}$$

And the carbon dioxide reacts with the carbon:

$$C + CO_2 + \text{heat} = 2CO$$

Methane leaving the gasifier is produced in the devolatilization step and to a lesser extent by the reaction:

$$C + 2H_2 = CH_4 + \text{heat}$$

Heat for the gasification process is supplied by partial or complete combustion of the residual carbon:

$$C + \tfrac{1}{2} O_2 = CO + \text{heat (partial combustion)}$$

$$C + O_2 = CO_2 + \text{heat (complete combustion)}$$

The product ash is cooled by the incoming steam and oxygen and removed through a lock hopper at the bottom of the gasifier. A synthesis gas composed of hydrogen, carbon monoxide, carbon dioxide, some sulfur compounds, methane and some higher hydrocarbons, leaves the top of the reactor vessel at 700°F to 900°F.

A potion of the crude gas from the gasifiers next passes through the shift conversion unit in which carbon monoxide and water are converted to hydrogen and carbon dioxide:

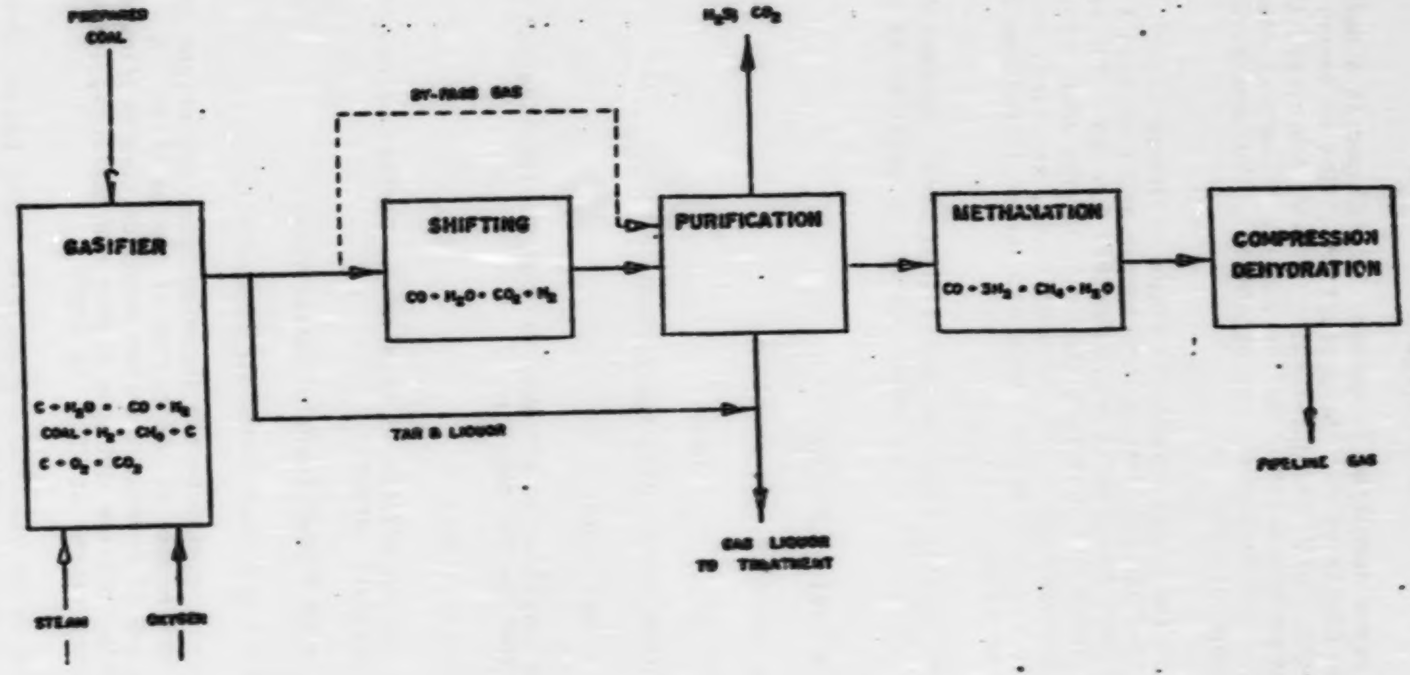
PREPARED COAL
GASIFIER
C + H2O = CO + H2
COAL + H2 = CH4 + C
C + O2 = CO2
STEAM
OXYGEN
BY-PASS GAS
SHIFTING
CO + H2O = CO2 + H2
TAR & LIQUOR
H2S CO2
PURIFICATION
GAS LIQUOR TO TREATMENT
METHANATION
CO + 3H2 = CH4 + H2O
COMPRESSION DEHYDRATION
PIPELINE GAS

FIGURE II-C.1-1 Schematic Representation of LURGI Gasification Process

$$CO + H_2O = CO_2 + H_2 + heat$$

This shift conversion is required so that the ratio of H_2 to CO in the methanation step will be about three.

The gas from shift conversion is recombined with the bypass gas and, after cooling, flows to the purification area. In the Lurgi process train, the proprietary Lurgi Rectisol unit is employed for gas cleaning. It uses low temperature methanol for physical absorption and removal of the sulfur compounds and reducing the CO_2 content of the synthesis gas.

The gas from the purification unit is converted to a high-BTU gas in the methanation unit which, using a pelleted nickel catalyst, combines carbon monoxide and hydrogen by the reactions:

$$CO + 3H_2 = CH_4 + H_2O + heat$$

$$CO_2 + 4H_2 = CH_4 + 2H_2O + heat$$

The methanation section employs fixed bed reactors and produces approximately 50 percent of the methane in the product gas. The other 50 percent has been previously produced in the gasifier. After methanation, the gas is dehydrated and compressed to approximately 1000 psia. Entering the pipeline it has a heating value of 950-1000 BTU/scf and a temperature of about 100°F.

In addition to the process train, a coal gasification plant will require facilities for steam and power generation, by-product recovery, oxygen production, raw water supply and treatment, waste water treatment, and process cooling.

II-C.2 Water Requirements

As stated previously, water is a primary resource required for synthetic gas production. It is used in both processing and cooling. In processing the water is used to generate steam and supply hydrogen for the reaction. It is also used for ash quenching and sluicing and for dust control and other applications in the mined areas. Large quantities of cooling water are required for the highly exothermic process.

a. Previous Water-Use Estimates

Several studies have been conducted to provide estimates of water requirements of a coal gasification industry. Nearly all the estimates assume a plant production capacity of 250 million scf/day. One such study was performed by the Institute of Gas Technology to identify and evaluate potential plant sites in Illinois[1]. The investigation was primarily concerned with utilization of the bituminous coal reserves in IGT's HYGAS Process[2]. However, it was noted that the minimum water requirement, in all processes available or under development, was about 2500 gal/min (0.16 cu m/sec or 3600 ac-ft/yr[3]) for the production of hydrogen and generation of steam. The OCR study[2] suggested that plant cooling requirements could increase the demand to 8500 gal/min (0.54 cu m/sec or 12,330 ac-ft/yr[3]) and that the actual requirement would fall within that range depending on the degree to which air cooling and water reuse are employed. Because of particular interest in the HYGAS Electrothermal Process, which requires additional water for hydrogen production, 10,000 gal/min was used by OCR as the minimum requirement.

Another study, prepared for the Environmental Protection Agency, provided a general assessment of the environmental impact of a large-scale coal gasification industry in the Rocky Mountain States[4]. Based on coal to gas conversion efficiencies, many of which were reported by Wen[5], Washburn estimated water requirements for a variety of processes under development. His calculations show that, depending on the process and the amount of air cooling employed, water consumption for a gasification plant with a 90 percent plant availability factor could fall between

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1. Seay, J. G.; Anderson, P. J.; Biederman, N. P.; and Ritter, B.; Evaluation of Sites for an Illinois Coal Gasification Industry; a report prepared for the Illinois Institute for Environmental Quality by the Institute of Gas Technology, Chicago, Illinois; May, 1972; 117 pp.
2. Office of Coal Research, Annual Report, 1973; pp. 31-34.
3. Assumes 90% production availability.
4. Washburn, Charles; "Environmental Impact of Large-Scale Coal Gasification Development"; a report prepared for the Environmental Protection Agency, Ecological Studies and Technology Assessment Branch; August, 1972.
5. Wen, C. Y.; Optimization of Coal Gasification Processes; Office of Coal Research R&D Report No. 66, Interim Report No. 1 & 2; 1972.

2,300 ac-ft/yr and approximately 12,000 ac-ft/yr. Calculations were also made to show that the cost of manufacturing the gas would be relatively insensitive to the cost of water, given its availability.

In a confidential siting study, the American Gas Association identified sufficient coal and water to support 141 gasification plants west of the Mississippi River. A Task Force, appointed by the Federal Power Commission to study the technical and economic aspects of coal conversion, reported on the site selection criteria used by the A.G.A.[1] The criteria presumed that a standard plant (250 million scf/day) using lignite as a feedstock and supplying cooling water makeup at a rate of 5 percent of the circulation would require nearly 19,000 gal/min with total evaporative cooling. The A.G.A. estimated the demand with "partial" air cooling to be half that amount or 9,500 gal/min (0.60 cu m/sec or 15,300 ac-ft/yr). With a makeup of 3 percent, which was considered minimum, the water requirement was reduced to 6,100 gal/min (0.38 cu m/sec or 9,800 ac-ft/yr).

b. Current Water-Use Estimates Based on Design

The best indication of the overall water requirements for a coal gasification plant utilizing the Lurgi Process may be obtained from those installations which have reached the planning and design stage. Two such plants have been announced for planned construction in the northwestern corner of New Mexico. El Paso Natural Gas Company is planning a 288 MM scf/day plant near Burnham while Western Gasification Company (WESCO), a joint venture of Texas Eastern Transmission Corp. and Pacific Lighting Corp., hopes to construct a 250 MM scf/day facility in the same vicinity. Because of the relative scarcity of water in the Four Corners area, the design of both plants will no doubt involve features which are applicable to the development of a gasification industry in the Northern Great Plains region. It is useful, therefore, to examine these proposed installations in terms of the plans for water utilization.

El Paso Natural Gas Co. Project

Detailed information on El Paso's coal gasification project may be obtained from filings made with the Federal Power Commission[2]. Preliminary designs show that the plant will produce 288 million cubic feet of gas (954 BTU/cuft) and consume 28,250 tons of sub-bituminous coal each day. The proximate analysis for this feedstock is shown in Table II-C.2-1. Net water consumption for the plant is estimated at 5,622 gal/min with total withdrawals at 7,056 gal/min to provide for evaporation from the raw water storage and service to the mine and users offsite. With the plant designed for a load factor of 91 percent, water consumption on an annual basis will be about 9,500 ac-ft/yr for the mining and gasification operations.

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1. Final Report of the Supply-Technical Advisory Task Force -- Synthetic Gas -- Coal; prepared for the National Gas Survey of the Federal Power Commission; April, 1973.
2. El Paso Natural Gas Company, Second Supplement to the Federal p Power Commission filing; Docket No. CP 73-131; October 9, 1973.

TABLE II-C.2-1

Characteristics of Feedstock for El Paso Complex

Fixed Carbon	33.85%
Volatiles	30.65
Ash	19.25
Moisture	16.25
	100.00%
Heating Value	8,664 BTU/lb

TABLE II-C.2-2

Characteristics of Feedstock for WESCO Complex

Fixed Carbon	33.8%
Volatile	28.2
Ash	25.6
Moisture	12.4
	100.00%
Heating Value	8,310 BTU/lb

With a limited supply in the region, the plant designers have attempted to economize on water consumption. The principle means of accomplishing this are the extensive use of air fin cooling and the treatment and reuse of process effluents. Cooling demand and heat requirements are also decreased by the extensive use of waste heat recovery for steam generation.

Figure II-C.2-1 is a simplified block flow diagram of the water utilization in the plant. It shows that nearly 75 percent of the treated raw water is directed to the gasifiers as steam and of that, 65 percent is effluent[1] which is produced by quenching and cooling the hot product gas. This gas liquor will contain tar, tar oil, and dissolved compounds such as phenols, ammonia, carbon dioxide, and hydrogen sulfide. Lacking predictive capability of contaminate levels, plant designers are unable to design treatment systems that will allow them to recycle this water to additional steam generation. After limited treatment, it is, however, used as cooling water makeup.

In cooling, large use is made of waste heat recovery and air cooling. The criterion which has been applied is that air cooling would be economically employed where processes temperatures were more than 45°F above the design dry bulb temperature[2]. For the plant site that temperature is 95°F. It is estimated that the heat rejection rates for the plant are 2×10^9 BTU/hr by air and 1.2×10^9 BTU/hr by cooling water.

As envisioned in the preliminary designs, two separate cooling water systems will be employed. One will circulate 8200 gpm to cool the pure oxygen streams. Cold water would leave the tower at 75°F and return at 90°F. Makeup to this clean system will be supplied by blowdown streams from the waste heat and power boilers at the rate of about 460 gpm. Blowdown from the cooling tower will be used as part of the makeup to the main system which will service the rest of the plant.

The main cooling system will circulate about 153,000 gpm with a cooling range of 15°F (90° - 75°F). As shown in Figure II-C.2-1, the main source of makeup is the effluent from the liquor treatment. Other makeup streams include 441 gpm of treated raw water, about 250 gpm of blowdown from the clean water system, and 20 gpm of treated sewage. Blowdown from the cooling system, operating at about seven (7) cycles of concentration, is approximately 330 gpm. This water will be used in the ash handling facilities or will be evaporated in large evaporation ponds. El Paso will try to eliminate

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[1] Only about 47% of the steam fed to the gasifiers is actually recovered as effluent. The balance of the effluent water comes from moisture in the coal.

[2] Clark, D., "Water Usage and Air Cooling: Coal-Fired Power and Coal Gasification Plants"; background report prepared for the Northern Great Plains Study Group; October, 1973.

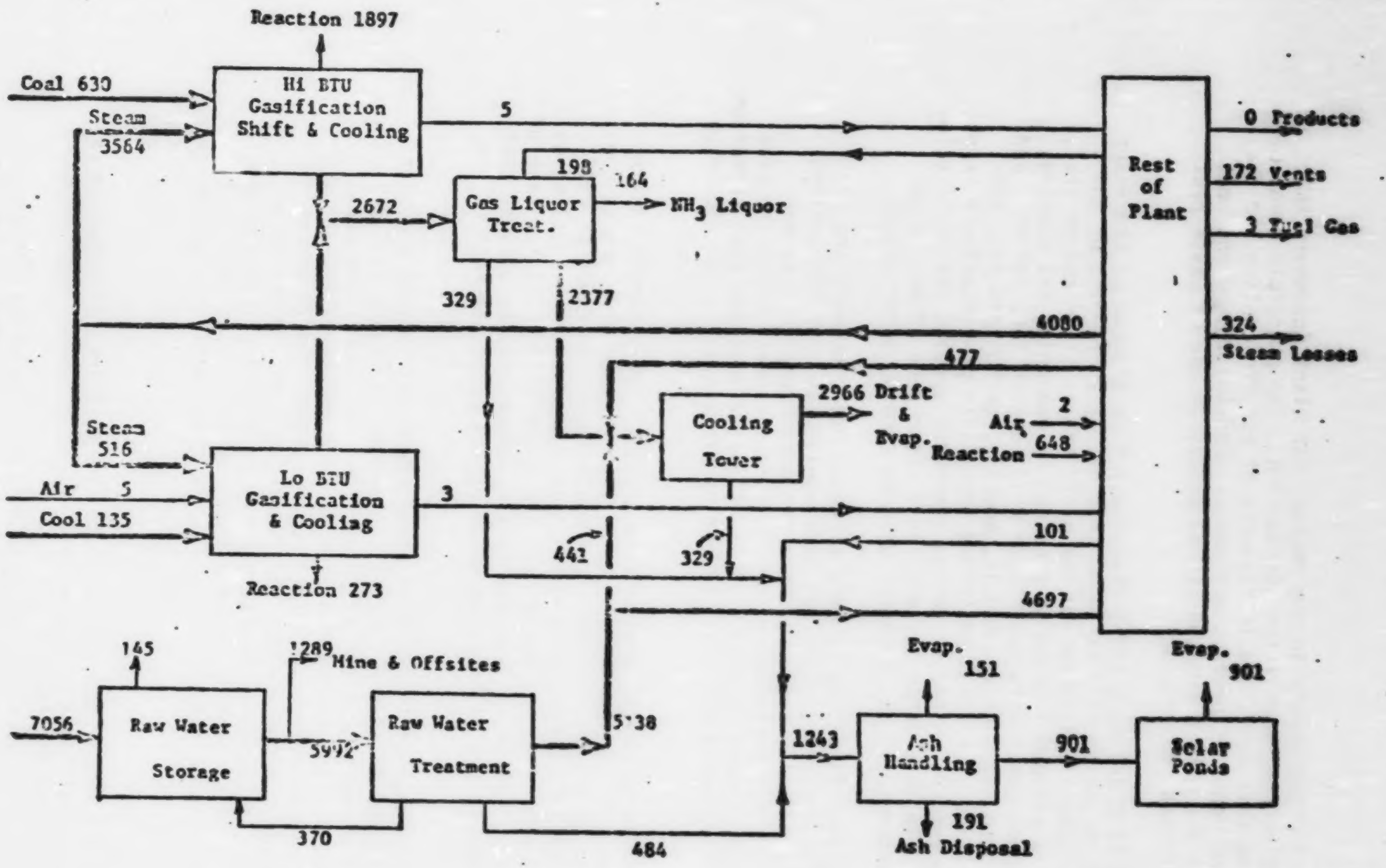
Reaction 1897
Coal 630
Steam 3564
Hi BTU Gasification Shift & Cooling
5
198
164
NH$_3$ Liquor
2672
Gas Liquor Treat.
329
2377
Rest of Plant
0 Products
172 Vents
3 Fuel Gas
324 Steam Losses
4080
477
2966 Drift & Evap.
Cooling Tower
Air 2
Reaction 648
Steam 516
Air 5
Cool 135
Lo BTU Gasification & Cooling
3
441
329
101
4697
Reaction 273
145
1289 Mine & Offsites
7056
Raw Water Storage
5992
Raw Water Treatment
5138
370
484
1243
Evap. 151
Ash Handling
191 Ash Disposal
901
Evap. 901
Solar Ponds

FIGURE II-C.2-1 Water Utilization (in gpm) for Coal Gasification Complex proposed by El Paso Natural Gas Co.

the need for the 441 gpm of raw water makeup[1]. That is a potential savings of 700 ac-ft/yr.

Western Gasification Company Project

Western Gasification Company has presented information on its proposed development in application with the Federal Power Commission[2] and in the environmental impact analysis[3]. The plans are for a plant to produce 250 million cubic feet of gas using 25,860 tons of coal per day. The composition of this feedstock is shown in Table II-C.2-2. Although this plant would use essentially the same process train as that envisioned by El Paso, it would employ several significantly different features with respect to the offsite facilities and utilities.

Water utilization in the plant is shown in the block diagram of Figure II-C.2-2. It shows that total withdrawals will be 5100 gpm (0.32 cu m/sec or 8250 ac-ft/yr). Like the El Paso installation, this plant will use effluent from the gas liquor treatment as makeup to the cooling tower, however, it will not require raw cooling water makeup as well. In part, this is due to a larger percentage of heat rejection by air cooling in the WESCO project[4]. The cooling system will circulate about 44,000 gpm with a range of 38°F (108°F to 70°F)[2]. That is a rejection rate of 0.84×10^9 BTU/hr. The cooling tower is to be operated at about five (5) cycles of concentration with a blowdown stream of 470 gpm used in ash quenching and handling.

c. Factors Influencing Water Consumption

One significant difference between WESCO's project and that planned by El Paso is the ultimate disposal of waste streams. El Paso's plant would use a portion of the waste water to dispose of ashes in the exhausted areas of the coal mine. The bulk of it would be evaporated from ponds, with the solid waste periodically being dredged for disposal. WESCO, however, would use the waste water in the mine, primarily for dust control, thereby reducing the raw water consumption by as much as 1500 ac-ft/yr and eliminating the need for evaporation ponds. Lower annual evaporation rates in the Northern Great Plains will necessitate substantially larger pond areas, thus making it more advantageous to dispose of the waste in some way other than evaporation ponds. The feasibility of utilizing the waste water in this manner will depend very much on the avoidance of potential

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1. Personal communication D. Clark, Stearns-Roger, Inc., February 26, 1974.
2. Western Gasification Company, Federal Power Commission filing; Docket No. CP-73-211; February 21, 1973.
3. Detailed Environmental Analysis Concerning a Proposed Coal Gasification Plant; prepared for WESCO by Battelle Columbus Laboratories; February 1, 1973.
4. Personal communication with M. Wooten, Texas Eastern Transmission Corp., March 1, 1974.

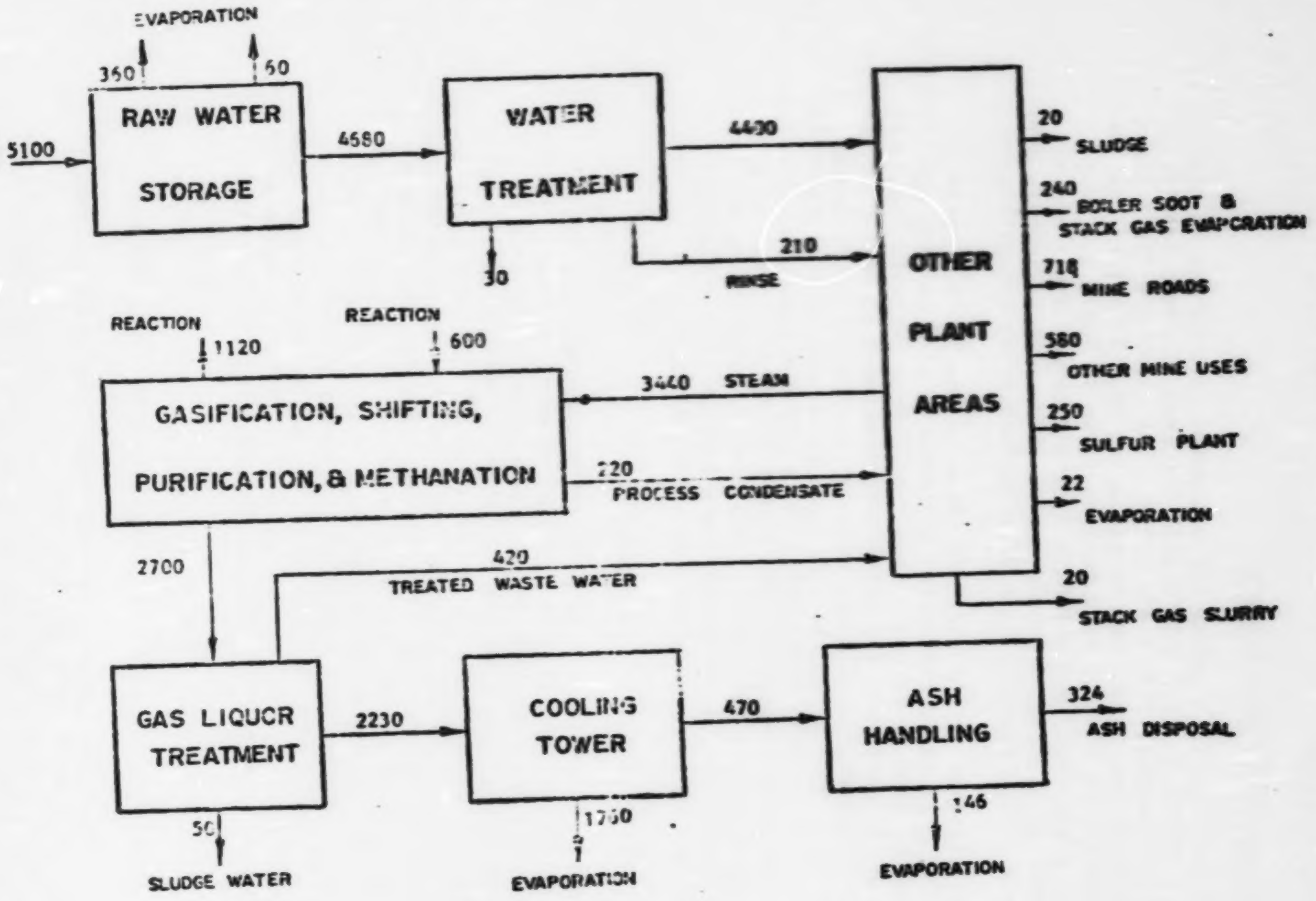
EVAPORATION
360
60
5100
RAW WATER STORAGE
4580
WATER TREATMENT
30
4430
210
RINSE
OTHER PLANT AREAS
20
SLUDGE
240
BOILER SOOT & STACK GAS EVAPORATION
718
MINE ROADS
580
OTHER MINE USES
250
SULFUR PLANT
22
EVAPORATION
20
STACK GAS SLURRY
REACTION
1120
REACTION
600
GASIFICATION, SHIFTING, PURIFICATION, & METHANATION
3440
STEAM
220
PROCESS CONDENSATE
2700
420
TREATED WASTE WATER
GAS LIQUOR TREATMENT
50
SLUDGE WATER
2230
COOLING TOWER
1760
EVAPORATION
470
ASH HANDLING
146
EVAPORATION
324
ASH DISPOSAL

FIGURE II-C.2-2 Water Utilization (in gpm) for Coal Gasification Complex proposed by Western Gasification Company

environmental problems associated with the leaching of salts, metals, and heavy hydrocarbons. El Paso's preliminary calculations show that the cooling tower blowdown may contain 400 ppm chlorides, 1400 ppm sulfates, 2000 ppm N as NH_3, and 10,000 ppm heavy organics[1]. Process condensates and other blowdown streams will contain substantial quantities of these and other constituents.

Another difference between the two installations planned for New Mexico is the fuel used to fire the boilers. El Paso will use low BTU gas produced from coal in air blown gasifiers while WESCO will use a coal fired power cycle. Calculations for the two companies show the plant utilizing the gas turbine cycle instead of a steam boiler cycle, which may require 200 to 400 gpm more water[2, 3]. For a region with abundant coal and limited water, the coal fired power cycle provides some potential for conserving water.

The degree to which process effluents can be treated and recycled will be another consideration in efforts to minimize water consumption. As mentioned previously, treatment of the gas liquor to boiler feed water is not yet easily designed prior to operation and the bulk of the stream requirements must be made up from the raw water supply. However, Panhandle Pipeline Co. of Houston has announced plans for a gasification plant for Wyoming for which it will attempt to develop treatment technology. If successful, it is anticipated that annual water consumption can be cut from about 8500 ac-ft to 6500 ac-ft[4]. The start-up of the previously announced plants may provide valuable information on effluent composition and process operation that can contribute to the development of treatment techniques.

A more fundamental factor influencing water consumption is the composition of the feedstock. Operation of the Lurgi gasifiers on New Mexico sub-bituminous will differ from operation on Wyoming sub-bituminous or North Dakota lignite. The Lurgi is a moving-bed, dry-ash gasifier and, as such, temperatures must be maintained below the ash melting point. Generally, the coals in the Northern Great Plains region have lower ash melting points than do the New Mexico coals. The steam/oxygen ratio determines the temperature in the combustion zone, with the steam serving as a cooling agent as well as a reactant. And, although less oxygen would be required for the more reactive northern coals, the steam required would be greater than for the New Mexico feedstock. One estimate is that the increase may be 20 to 30 percent which, as a minimum, would be an additional 700 gpm for the

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1. Personal communication with M. Holland, El Paso Natural Gas Co., January 31, 1974.
2. Clark, D., "Water Usage and Air Cooling: Coal-Fired Power and Coal Gasification Plants"; background report prepared for the Northern Great Plains Study Group; October, 1973.
3. Detailed Environmental Analysis Concerning a Proposed Coal Gasification Plant; prepared for WESCO by Battelle Columbus Laboratories; February 1, 1973.
4. Personal communication with R. Newsom, Panhandle Eastern Pipeline Co., January 14, 1974.

El Paso complex[1]. The actual steam requirement is, of course, dependent on the particular coal which can be highly variable. Nonetheless, any increase in the steam requirement approaching 30 percent will provide additional incentive to develop techniques for recycling the process condensate.

Another factor associated with the coal is the moisture content, with the northern coals generally being higher in moisture. The lignites can have a moisture content of 30-40 percent as compared with 12-16 percent for the New Mexico coals. The higher moisture content will no doubt require that the coals be at least partially dried prior to being fed to the gasifier. If the water driven off in the drying process can be recaptured and used in steam generation, it can amount to a substantial reduction in water consumption. If the quality of the condensate is such that it cannot be used for steam, it will be available for other purposes such as cooling water makeup. Irrespective of water use, gasification of the northern lignites will require larger volumes of feedstock given the lower energy content as compared with the southwestern sub-bituminous.

The degree to which evaporative cooling is employed will be dependent on two closely associated factors: the availability of makeup water and the economic feasibility of air cooling. Until means are employed to recycle the gas liquor to steam generation, there will be a quantity of water available for cooling water makeup. The same is true of the boiler blowdowns which are used for that purpose. Because these streams must be discarded anyway, plant designers will logically cycle them through an evaporative cooling system prior to disposal. If, as previously discussed, the waste water is of such quality that it cannot be applied in the mined areas, the evaporative cooling is a means of reducing the volume and concentrating the wastes. Less land would, therefore, be required for evaporation ponds if that were the ultimate means of disposal. Again, the effect is important in the Northern Great Plains with lower net evaporation rates.

Dry cooling, either direct or indirect, should be more feasible in the northern states since the design dry bulb may be as much as 10°F lower than the 95°F used for the New Mexico installations. An accurate determination of the extent to which air fin cooling can be employed will depend on the process temperatures and pressures. One estimate was made of the potential water savings which could be accrued by using an air cooled refrigeration cycle in the bas purification unit of the El Paso plant[1]. The preliminary designs show that the refrigeration cycle rejects about one-tenth of the total heat removed by cooling water. The use of air cooling could save about 330 gpm (540 ac-ft/yr) with some increase in capital expenditures and horsepower requirements.

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[1] Clark, D., "Water Usage and Air Cooling: Coal-Fired Power and Coal Gasification Plants"; background report prepared for the Northern Great Plains Study Group; October, 1973.

II-C.3 Prospects for the Future

In addition to the Lurgi, there are several pressurized gasification processes under development, four of which have reached or are approaching the pilot plant stage. These processes are:

1. HYGAS by the Institute of Gas Technology
2. BI-GAS by Bituminous Coal Research
3. CO_2 Acceptor by Consolidation Coal Company
4. SYNTHANE by the Bureau of Mines

The first three are also sponsored by the Department of the Interior's Office of Coal Research. Detailed descriptions of the individual processes are available in the literature[1, 2, 3, 4]. Differences in the various processes include the manner in which materials are reacted, the methods of providing energy, the temperatures and pressures to attain reaction rates and material flow. All these variables will figure into the water requirements for a commercial installation.

The Office of Coal Research has retained C. F. Braun & Co. of Alhambra, California for this purpose of evaluating and assisting in the optimization of process development. As part of the effort, they will complete conceptual designs for commercial installations of the four processes. These designs will provide estimates of water and other resource requirements for these newer processes. The preliminary investigations show that the newer processes will require slightly less water than the Lurgi. In part, this is due to the more efficient use of the process steam at a high pressure and temperature. Potentially more important is the possibility that these systems will produce a cleaner gas and have a condensate which is easier to recycle to steam generation than is the case with Lurgi[5]. At this early stage in process development, the best estimate of minimal water requirements for these second generation plants is 6000 ac-ft/yr[6].

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[1] Office of Coal Research, Annual Report, 1973; pp. 31-34.

[2] Final Report of the Supply-Technical Advisory Task Force -- Synthetic Gas -- Coal; prepared for the National Gas Survey of the Federal Power Commission; April, 1973.

[3] Hottel, H. C. and Howard, J. B.; New Energy Technology - Some Facts and Assessments; Cambridge, Mass.; 1971; 364 pp.

[4] Schurr, S. H.; Energy Research Needs; Resources for the Future; October, 1971, 893 pp.

[5] Personal communication with R. Detman, C. F. Braun & Co., Inc., February 26, 1974.

[6] Personal communication with N. Cochran, Office of Coal Research, January 15, 1974.

The development of individual downstream process units could also influence overall cooling demand. For instance, the Lurgi Rectisol Gas purification system requires a refrigeration cycle with substantial heat rejection. Some of the newer processes for gas clean-up will operate at near ambient conditions and may, therefore, require less cooling.

One gasification process which has the potential for conserving water is a low pressure, rapid pyrolysis system being pursued by Garrett Research and Development Co., Inc.[1] Process developers estimate that the water consumption in a plant producing 250 MM scf/day can be held to less than 3000 gpm (0.19 cu m/sec or 4850 ac-ft/yr). However, the system would require up to 60 percent more coal than the Lurgi and produce substantial quantities of ash and char for disposal. It is envisioned that the char, with an energy content of 12,000 BTU/lb, would be used to generate electricity. Because many of the impurities would be concentrated in the char, such use would require measures to avoid air pollution.

In the future, as processes are developed, it may be more practical in terms of resource utilization to establish large-multi-product type installations. These "coal refineries" would use a liquefaction process to produce a liquid fuel as well as a gasification process to produce low-BTU fuel gas and substitute natural gas. The preliminary design for one such facility which would produce liquid boiler fuels to generate 620 MWe of electricity estimates the water consumption at 3600 gpm. The plant is designed for 10,000 tpd of bituminous feedstock[2].

Using this coal refinery concept, the Office of Coal Research is conducting research into the potential environmental impacts of the mine/refinery operation and the measures required to minimize those impacts. One aspect of the investigation is the effect of the plant on the water resources of the area. The first phase of the study will be concerned with plant operation in any of four regions of the country: The Appalachian coal fields, the Illinois Basin with western Kentucky and Indiana, the Four Corners area, and the Fort Union Lignite deposits. The second phase would involve a detailed look at a single region[3, 4].

The Environmental Protection Agency's Control Systems Laboratory is also investigating the environmental effects associated with coal

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1. "Occidental Develops Low-Cost SNG Route"; Chemical and Engineering News; December 19, 1973; pp. 23-24.
2. Ralph M. Parsons Co.; Demonstration Plant-Clean Boiler Fuels from Coal; Office of Coal Research R&D Report No. 82, Interim Report No. 1; 77 pp.
3. Detailed scope of work for a study on the environmental protection of coal refining operations to be conducted by Hittman Associates, Inc. for the Office of Coal Research.
4. Personal communication with J. O'Shaughnessy and J. Geffkin, Office of Coal Research, February 7, 1974.

conversion. Although primarily directed to air pollution control, this study will generate much information on liquid effluents[1, 2].

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[1] Detailed scope of work for a program of study on environmental control achieved from fuel conversion processes to be conducted by ESSO Research and Engineering for the Environmental Protection Agency.

[2] Personal communication with L. Lorenzi, Environmental Protection Agency, February 11, 1974.

II-C.4 Summary and Conclusions

Because there are no prototype installations for producing pipeline quality gas from coal, estimates of water consumption for such an operation must be based on preliminary information. The number of variables which can influence the plant requirements for water include the composition of the feedstock, the character of the effluents and means for recycling them, the type of power cycle employed, and the feasibility of air cooling. On the basis of presently available information, it is estimated that a coal gasification plant using the Lurgi Process and producing 250 MM scf/day of synthetic natural gas will require 6000 to 10,000 ac-ft (7.40×10^6 to 12.33×10^6 cu m) of water per year.

The ability of the plant designer to achieve the lower limit will depend on the development of techniques to recycle the process condensate and maximum use of air cooling. The start up of announced plants and the continuation of on-going research in process development will provide much information to quantify water consumption for a given system and feedstock. Ultimately, the water demand for a particular plant will be highly dependent on the ingenuity of the plant designer and the availability of raw water makeup.

For quantification of water consumed per unit of energy produced, the gasification plants planned for New Mexico[1, 2] provide a basis for comparison. Disregarding by-products, the energy contained in the product gas is about 2.5×10^5 BTU for each cubic foot of water consumed in the gasification process. Putting it in terms of the electrical equivalent, this is about 0.4 cu m/MWH. This may be compared with the water required for conventional steam electric power generation. With evaporative cooling, such requirements are typically about 2.0 cu m/MWH. This comparison, of course, neglects the conversion of the energy to an end use.

The gasification processes also promise to be more efficient in the utilization of coal resources than is conventional power generation. Again disregarding the energy content of the by-products, the conversion of coal to gas will be about 60 percent efficient. This is compared with an efficiency of 38 percent in a fossil-fuel power plant. Of course any comprehensive comparison of the two forms of energy conversion must consider a much wider range of variables and the fact that the energy forms are not equivalent.

To provide the tools required for long range planning for resource utilization, it is recommended that:

1. Research be continued to more accurately determine the water resource requirements of a coal gasification industry in the Northern

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1. El Paso Natural Gas Company, Second Supplement to the Federal Power Commission filing; Docket No. CP 73-131; October 9, 1973.
2. Western Gasification Company, Federal Power Commission filing; Docket No. CP-73-211; February 21, 1973.

Great Plains. In this endeavor, coordination must be maintained with process developers and plant designers. Maximum use must be made of information generated by research on the environmental impacts of coal conversion already in progress. Inasmuch as most of this research is in the preliminary stages, it will be some time before it is available.

2. The production of products other than synthetic natural gas will involve other coal conversion processes with different resource demands. These processes (i.e., liquefaction and fuel gas manufacture) should also be considered as alternatives for coal utilization.

3. This section contains no information with which to compare coal conversion processes on the basis of cost. Such information will be important to the consumer of energy and additional effort should be devoted to providing it. As with water usage, accurate information on the capital and operating costs for many of the newer conversion processes must await further development.

CHAPTER III

STREAM FLOWS USED FOR WATER QUALITY ANALYSES

III-A Introduction

A basic assumption that has always accompanied development of water resources is that some water from each stream can be removed from the stream and used to support a project needing water, with little impact to the stream. In other words, providing some certain amount of water is left behind, there is no substantial impact on the aquatic (and nearby terrestrial) ecosystem of such diversions. Given that western streamflows vary both throughout any given year and from year to year, the assumption seems reasonable at first. The increasingly vivid questions, however, are how much water must be left in the stream to adequately protect "instream values" and how important to the aquatic ecosystem are the variations in flow.

Before it is possible to estimate how much water is "available" for coal development in the NGP; before it is possible to assess water quality impacts; before it is possible to assess fisheries impacts; and therefore before it is possible to assess the impact of coal development on the water resources of the NGP, a methodology must be available that will provide an estimate of the minimum flow allowable for each stream that would preserve essentially the nature and levels of fishery and other stream-related resources that exist in the NGP today. No such methodology exists today that has been field tested and verified.

Even though a field tested methodology was not available for use in the NGPRP, it was felt that an estimate of "instream needs" would facilitate examination of water development alternatives, primarily in two ways: (1) it would be possible to examine the amounts and locations of water available for diversion and use that (in theory) would be more or less unencumbered by "environmental" implications; (2) the estimates would provide "critical points of departure" against which the relative environmental impacts of various development alternatives eventually examined could be evaluated.

An Instream Needs Subgroup (to the Water Work Group) was formed under the direction of Gary Wood of the Bureau of Sport Fisheries and Wildlife and asked to develop an "instream needs" flow estimate for each stream likely impacted by coal development in the NGP. Since no meaningful field effort was possible, the work had to be a "desk top" analysis using existing data. A methodology was developed, discussed, modified, and agreed upon for use in the NGPRP. The methodology used was the best available and based on reasoned biological judgement. However, from the very beginning, it was recognized that further methodology refinement was necessary.

To satisfy the need for such a methodology, EPA has contracted with the University of Montana to design a detailed measurement system that will allow, once implemented, the assessment of impact on the aquatic (and terrestrial if appropriate) ecosystem as the result of streamflow modifications in the NGP. This study will define the state-of-the-art in evaluating instream needs, review past and present efforts in developing instream needs methodologies, and synthesize a new methodology applicable to the NGP. The initial report is scheduled to be published by the Northern Great Plains Resources Program.

EPA has arranged with these same researchers to field test and verify the methodology developed. A field verification would consist of 1) an assessment of the occurrence and distribution of organisms in the Tongue River (as a representative stream in the NGP); 2) application of the methodology to the Tongue River to predict allowable minimum flows; and 3) the temporary establishment of an in-situ "laboratory" on the Tongue River where lower flows can be synthesized and the methodology predictions verified.

In following discussions of the impacts of coal development on water quality, the flow rates developed by the Instream Needs Subgroup have been used for much of the analysis. In other cases measured average monthly flows have been used. Tables III-A.1 through III-A.6 show the flow rates used in the quantitative analysis of impacts in Chapter IV. The use of "Instream Needs" flows (and average flows) in some cases is somewhat arbitrary. For example, the flow rates shown as the "instream need" for a stream are inherently not met when natural flows are lower than the designated "instream need flow rate." The analysis, based on instream need flow rates, does not cover this "worst possible case." On the other hand, "instream need" flow rates are still used when the water requirement for a given plant would not require all of the water provided for by new storage hypothetically proposed by the Water Work Group as needed for a given plant. In this case the impact estimates are probably high. In summary, the flows used are only representative. Even if development were to occur such that the minimum Instream Needs Subgroup flows were just met, it must be remembered that these flows are preliminary estimates, which make all analyses based on these flows, preliminary.

The use of water in development, water above or below that amount needed for instream needs, is dependent on complicated water right laws. In Appendix III of this report is a discussion of Indian water rights questions which serve as an example of this complex issue. Thus water to meet instream needs is not the only demand for water in these relatively water short areas.

TABLE III-A.1

Flows Used for Analysis - Bighorn River at Bighorn, Montana

(cfs)

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly Average	4000	4400	5600	4700	4800	6000	5500	3200	2800	2500	4300	3300
Instream Water Needs	2100	2100	2100	2100	2100	3400*	1800	1800	1800	1850	2100	2100

* Flows may need adjustment to provide gradual changes in water level.

TABLE III-A.2

Flows Used for Analysis - Tongue River at Miles City, Montana

(cfs)

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly Average	173	446	631	583	843	1885	558	186	252	219	194	161
Instream Water Needs	135	135	200	230	425	425	370	100	100	100	100	135

TABLE III-A.3

Flows Used for Analysis - Powder River at Moorhead, Montana

(cfs)

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly Average	136	253	690	574	1022	1542	541	150	126	184	203	159
Instream Water Needs	100	100	300	300	450	400	120	30	30	100	100	100

TABLE III-A.4

Flows Used for Analysis - Yellowstone River at Billings, Montana

(cfs)

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly Average	2424	2684	3027	4042	12465	26488	14147	5260	4158	3941	3591	2793
Instream Water Needs	1950	1950	2100	2350	7500	7500	7500	3600	3200	3100	2650	2250

TABLE III-A.5

Flows Used for Analysis - Yellowstone River at Miles City, Montana

(cfs)

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly Average	4696	5377	8163	7821	16921	37397	21064	7570	6841	7309	6687	5207
Instream Water Needs	3600	3600	4400	4600	10500	10500	10500	5100	5100	5100	4800	4500

TABLE III-A.6

Flows Used for Analysis - Yellowstone River at Sidney, Montana

(cfs)

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Monthly Average	5470	6485	11033	9367	16780	38960	30661	10848	9428	7666	7365	5689
Instream Water Needs	3400	3500	4400	4600	12000	12000	12000	4000	4000	4000	4000	4000

III-B Flows Used In Calculations

To facilitate the TDS projections resulting from coal and associated development, the first requirement is to obtain data on the present concentration of total dissolved solids in rivers of the region. Since the projections are to be made for each month of the year, the average monthly TDS concentrations (for the last five years of record) were calculated for the required water quality stations. These data are used to allow comparison with projected concentrations as well as to make these projections.

Two different flow rates can be analyzed, depending upon the impact of the water supply system on the river being considered. For rivers where reservoir and aqueduct development was likely to impact the flow, the flows from the water supply study of the Water Work Group were used. The water supply studies model the effects of aqueduct and reservoir operation and project new flows given estimated deliveries and depletions for coal development. Return flows from coal gasification and power generation plants are added to these supply study flows in accordance with the assumed discharge location. In all other cases, the 1970 level monthly flows are used with return flows from coal-conversion facilities added as appropriate. No new reservoirs or aqueducts are considered to perturb the flows. Tables III-B.1 through III-B.4 give flows based upon the water supply study flows and the 1970 level flows. These flows were used in the calculations of TDS in the following chapter.

TABLE III-B.1

Projected Flows for the Yellowstone River at Miles City, Montana

Month	1970 Level Flow (1000 Acre-Feet/Month)	Projected Flow* (1000 Acre-Feet/Month) Year 2000		
		CDP I**	CDP II	CDP III
January	310.7	(same as 1970 level flows since not impacted by postulated CDP I development)	295.4	244.2
February	331.8		311.7	259.7
March	502.1		466.4	421.4
April	470.5		438.9	384.0
May	1009.5		938.6	871.6
June	2132.7		2023.7	1956.1
July	1264.2		1196.2	1128.4
August	473.1		443.3	388.0
September	423.9		396.7	332.2
October	490.5		443.4	380.9
November	429.0		403.3	346.4
December	348.4		331.3	276.7
Annual Average	8186.4	8186.4	7688.9	6989.5

* Total projected flows for this river may be obtained by adding the estimated coal-conversion plant discharges of 0.0, 2.5-5.0, and 8.3-16.7 thousand acre-feet per month respectively to the projected flows listed above for CDPs I through III. The range in effluent discharges within a CDP corresponds to the estimated range of discharge for coal gasification plants.

** Coal Development Profile

TABLE III-B.1

Continued

The monthly flows were obtained from computer printout supplied by the Bureau of Reclamation office in Billings. These flows do not, as indicated, include discharges from coal conversion facilities but the specified amounts may be added to each monthly flow depending upon one's choice of 10,000 or 20,000 acre feet discharge from gasification plants (power plant discharges are a constant 5000 acre feet).

More specifically, figures in Column 1 were obtained from printout titled "First Choice - Most Probable Forecast Ind. Div: Hardin = 183,000 AF. Armells Creek = 139,500 AF. Yellowstone River at Miles City Summary of 1970 Lvl." (bottom row) provided the authors.

CDP II data were obtained from printout titled "First Choice - Most Probable Forecast...Summary of Regul. Outflow" (bottom row) also provided the authors.

CDP III data were obtained from printout titled "0.55 Flow, Bighorn River Basin, Ind. Div. at Boysen = 0 AF, Ind. Div. @ Hardin = 833,300 AF...Summary of Regul. Outflow" (bottom row) provided the authors.

TABLE III-B.2

Projected Flows for the Tongue River at Miles City, Montana

Month	1970 Level Flow (1000 Acre-Feet/Month)	Projected Flow* (1000 Acre-Feet/Month) Year 2000		
		CDP I	CDP II	CDP III
January	11.1	9.9	(same as 1970 level flows)	(same as 1970 level flows)
February	12.7	9.9		
March	33.9	26.8		
April	29.5	23.4		
May	40.9	28.8		
June	84.4	49.9		
July	27.0	23.9		
August	6.4	6.2		
September	10.3	8.4		
October	16.6	13.9		
November	18.6	16.4		
December	13.0	11.0		
Annual Average	304.4	228.4	304.4	304.4

* Total projected flows for this river may be obtained by adding the estimated coal-conversion plant discharges of 1.3, 3.8-6.2, and 5.5-9.6 thousand acre-feet per month respectively to the projected flows for CDPs I through III. The range in effluent discharges within a CDP corresponds to the estimated range of discharge for coal gasification plants.

TABLE III-B.2

Continued

Nineteen-seventy level flow data were obtained from a hand-printed summary sheet provided this office titled "Flow Data For Use in NGPRP Water Quality Evaluation (Sheet 1 of 2)". This corresponds with the printout of 1970 level runoff. CDP I flows were obtained from a printout titled "Tongue River Basin, New Tongue Reservoir (Act. Cont. = 316,000 AF) Ind. Div. = 63,000 AF. Tongue River at Miles City - Summary of Regul. Outflow" (bottom row) provided to this office.

TABLE III-B.3

Projected Flows for the Powder River at Moorhead, Montana

Month	1970 Level Flow (1000 Acre-Feet/Month)	Projected Flow* (1000 Acre-Feet/Month) Year 2000		
		CDP I	CDP II	CDP III
January	8.6	5.9	10.4	(same as 1970 level flows)
February	13.7	7.9	11.6	
March	40.7	31.2	28.9	
April	32.8	24.9	22.7	
May	60.5	53.0	42.3	
June	87.7	77.6	68.0	
July	27.5	19.3	19.1	
August	9.4	4.3	7.7	
September	7.6	3.3	7.0	
October	11.2	6.1	12.9	
November	11.9	7.3	12.2	
December	10.2	6.3	11.7	
Annual Average	321.8	247.1	267.4	321.8

* Total projected flows for this river may be obtained by adding the estimated coal-conversion plant discharges of 0.5, 2.2-3.8, and 6.3-12.2 thousand acre-feet per month respectively to the projected flows for CDPs I through III. The range in effluent discharges within a CDP corresponds to the estimated range of discharge for coal gasification plants.

Data in Column 1 were obtained from the same source used for Table III-B.2. CDP I and II estimates were acquired from the Bureau of Reclamation (Billings) via telephone.

TABLE III-B.4

Projected Flows for the Yellowstone River at Sidney, Montana

Month	1970 Level Flow (1000 Acre-Feet/Month)	Projected Flow* (1000 Acre-Feet/Month) Year 2000		
		CDP I	CDP II	CDP III
January	319.6	315.0	304.7	252.2
February	365.1	345.6	345.0	289.0
March	662.7	711.6	627.0	572.6
April	581.8	640.1	550.1	488.3
May	992.1	943.7	927.6	852.7
June	2225.1	1948.7	2116.1	2052.7
July	1318.9	1298.6	1252.0	1190.6
August	446.8	444.0	417.0	363.5
September	395.3	381.1	368.2	303.8
October	500.4	457.8	453.2	390.9
November	441.7	417.2	415.9	358.2
December	347.9	334.7	331.1	276.3
Annual Average	8597.4	8238.1	8108.07	7390.8

* Total projected flows for this river may be obtained by adding the estimated coal-conversion plant discharges of 1.8, 814-15.1, and 70.2-38.5 thousand acre-feet per month respectively to the projected flows for CDPs I through III. The range in effluent discharges within a CDP corresponds to the estimated range of discharge for coal gasification plants.

TABLE III-B.4

Continued

1970-level flows were initially obtained from a computer printout titled "Summary of 1970 Lvl. Runoff, Yellowstone River at Mouth", bottom row (average) and then were obtained from the source referenced on Table III-B.2. CDP I data are obtained by adjusting 1970-level flows for Tongue and Powder River Reservoirs.

CDP II data were obtained from printout titled "First Choice - Most Probable Forecast. Yellowstone River at Mouth, Summary of Regul. Outflow."

CDP III data were obtained from printout titled "0.55 flow, Bighorn River Basin, Ind. Div. at Boysen = 0 AF, Ind. Div. at Hardin = 833,300 AF, Yellowstone River at Mouth, Summary of Regul. Outflow."

CHAPTER IV

WATER QUALITY IMPACTS OF COAL DEVELOPMENT

Chapter IV contains a presentation of the "Analysis of Consequences" of various levels of coal development on water quality in the NGP. Sections 1 and 2 deal with quantitative impacts for total dissolved solids and dissolved oxygen for the three scenarios used by the NGPRP to represent varying levels of development. Section 3 deals with other impacts that are expected, or possible, but that cannot be quantified in view of the inadequacy of today's data base. The discussion is qualitative in nature, but shows how larger levels of development can be expected to result in greater impacts than smaller levels of development. Section 4 deals with potential water quality impacts associated with the construction of impoundments on free flowing streams in the NGP. Section 5 briefly discusses the alternative type of impacts that should be considered because of different siting possibilities.

IV-A.1 Projections of Total Dissolved Solids Concentrations for Northern Great Plains Coal Development

Projections of possible future total dissolved solids (TDS) concentrations at selected sites have been made for each NGPRP coal development scenario. These projections are based entirely on estimates of consumptive use of water by coal-energy conversion plants and do not include any further TDS increases caused by runoff from disturbed areas, leaching of mine spoils or irrigation return flows. The objective, the necessary assumptions, and the use of data are discussed in detail. The model and methodology used to make these TDS projections was explained in Chapter I. The flows used were listed in Chapter III. The results are displayed and discussed for all three scenarios. A summary of the results discusses the basic insights developed in making these projections.

The methodology discussed in Chapter II utilizes the projected stream flows for each profile and average TDS concentrations (from 5 years of record) on a monthly basis to project TDS concentrations at the following locations: The Tongue River at Miles City, Montana; the Powder River at Moorhead, Montana; the Yellowstone River at Miles City and Sidney, Montana; and the Missouri River at Bismarck, North Dakota. The calculated average TDS concentration is used as the measure of the ambient concentration at these locations prior to discharge and in certain instances as the intake concentration to a postulated plant from which the effluent concentration is then determined. The "historic" TDS concentrations are summarized in Table IV-A.1-1.

To repeat, a 1000 megawatt power plant is assumed to need 19,000 acre-feet of water per year and to discharge 5,000 acre-feet of this water per year. These assumptions result in an effluent TDS concentration of 3.8 times the intake concentration and are used to calculate the TDS concentration in projected power plant effluents. The calculated effluent TDS is added to the average monthly TDS for the stream in proportion to the flows as indicated by equation 1 shown on page 162.

Gasification plants were first assumed to need 30,000 acre-feet of water per year and to discharge 20,000 acre-feet. Since in many cases this resulted in a TDS effluent concentration of 1.5 or much lower than is likely[1], it was also assumed that the plant would reuse water until the TDS concentration is increased three-fold or discharge only 10,000 acre-feet. Both sets of assumptions are used to project future TDS levels. Again, the gasification plant effluent was added to the stream in proportion to the flows. It is recognized that far too much water is projected for use in a gasification plant.

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[1] It might be expected that the quality of effluent discharged by plants of any type to approach the maximum contaminant levels permitted under federal and state regulations wherever re-use of water is necessitated by limitations of water supply. As of yet limits on TDS for power generation and coal gasification plants have not been set.

TABLE IV-A.1-1

Average Monthly Total Dissolved Solids Concentration*
(mg/l or ppm)

Month	Tongue River at Miles City, Montana	Powder River at Moorhead, Montana	Yellowstone River near Miles City, Montana	Yellowstone River at Sidney, Montana	Missouri River at Bismarck, North Dakota
January	723	1300	580	553	424
February	682	1050	499	464	425
March	487	1050	517	516	427
April	610	1500	488	594	466
May	612	1450	377	419	438
June	325	950	236	290	443
July	425	1600	302	323	447
August	468	2650	392	425	455
September	508	2150	438	439	439
October	689	1750	430	505	452
November	689	1700	489	526	450
December	818	1550	507	583	429
Annual Average	586	1558	438	470	441

* Monthly values are calculated from past five years of measurements at each station.

These assumed water usage and discharge rates for coal-conversion plants are based on the possibility that plants will use larger than necessary amounts of water and will therefore have a substantial discharge. Should institutional and water cost constraints dictate the use of smaller quantities of water and therefore possibly a very low or no effluent discharge, the projected changes in TDS concentrations resulting from coal-conversion will be much less than indicated by these results, by virtue of the significantly lesser discharges.

The following assumptions must be remembered when using this method to project future TDS concentrations:

1/ The hydrologic mechanisms which cause the concentration of TDS to be inversely related to the stream flow rate will not be substantially altered by development in the region.

2/ New development activities other than power and gasification plants will have a negligible impact on future TDS concentrations.

3/ Estimates of the use and consumption of water by power and gasification plants are reasonable and, therefore, provide reasonable estimates of their effluent quality and quantity. (This remains questionable.)

Although the existing mechanisms which related TDS to stream flow could be altered by water resource development, this first assumption is necessary without data to support differing assumptions. The second assumption ignores the potential impact from new irrigation, mine drainage, and other industries. However, at this time data are not available to even roughly estimate the impact of these activities for the whole or even large portions of the region. The estimates of water use requirements are selected to be consistent with other NGPRP work groups but are also recognized as too high.

These projections, presented in the following section, should be considered first estimates which can and should be improved as more information becomes available. For now, the results of this analysis can serve to relate the possible impact on one water quality parameter, total dissolved solids, resulting development of electrical power generation and coal gasification facilities.

IV-A.2 Results of TDS Projections

a. Introduction

The results of the TDS projections for the year 2000 are given for each coal development profile. For each profile, only the "first choice" of two choices for water supply systems calculated by the Water Work Group is analyzed. As mentioned earlier, these supply systems differ substantially from scenario to scenario and, therefore, result in some otherwise unexpected differences in basin impacts (see Section IV-A.1-1b). Not all impacts are analyzed for each scenario, but those shown should give individuals and governmental agencies a feel for the degree of change in TDS which can result from development.

A range in the projected TDS concentration is given for each month. The lower concentration was calculated using a TDS concentrating factor of 1.5 for gasification plants; the higher number determined using a factor of 3.0 for gasification plants. The 1.5 factor results from use of 30,000 AF/yr and discharge of 20,000 AF/yr. The 3.0 factor results from use of 30,000 AF/yr and discharge of 10,000 AF/yr. Where no gasification plants were projected to be located upstream of the point of analysis, a range was not calculated but instead only one concentration was determined which reflects the estimated impact of upstream power generation plant (only) development based upon the concentration factor of 3.8.

The locations where TDS projections are made correspond to water quality station locations and were selected for determining tributary, river basin, and regional impacts. The projections made for the Yellowstone River at Miles City, before the confluence with the Tongue River, indicate overall upstream impacts resulting from Bighorn River Basin depletions and coal-conversion plants located in the Sarpy, Armells and Rosebud Creek drainages. More local impacts have not been analyzed because of modeling difficulties for the Bighorn River, where depletions should increase the TDS concentration, and because of insufficient TDS data for the potentially impacted tributaries. TDS projections for the Tongue and Powder Rivers indicate the potential impact to these tributaries from location of coal-conversion facilities along with potential reservoir development within the basins. The projections for the Yellowstone River at Sidney combine the effects of all upstream plant discharges and water resource development and indicate the potential impacts to the Yellowstone River Basin as a whole. The annual TDS projection made for the Missouri River at Bismarck, North Dakota, extends the impacts within the Yellowstone, Knife and Heart Rivers to the Missouri River.

b. Yellowstone River at Miles City, Montana

Table IV-A.2-1 gives the results of the TDS projections for the Yellowstone River at Miles City. By the year 2000 and in CDP III, the average annual flow of the Yellowstone is projected to be depleted by

TABLE IV-A.2-1

Total Dissolved Solids Projections for Yellowstone River at Miles City, Montana

Month	Present Calculated Average TDS (mg/l)	Projected TDS Concentration (mg/l)		
		CDP I Year 2000	CDP II Year 2000	CDP III Year 2000
January	580	No change projected	579 - 584*	576 - 596*
February	499		499 - 503	501 - 516
March	517		517 - 570	517 - 527
April	488		488 - 491	490 - 500
May	377		378 - 379	380 - 383
June	236		237 - 237	238 - 239
July	302		303 - 304	305 - 307
August	392		393 - 396	397 - 406
September	438		439 - 442	442 - 453
October	430		431 - 433	434 - 443
November	489		489 - 492	491 - 502
December	507		507 - 511	508 - 523
Annual Average (rounded)	438 (5-year average)		440 - 440	440 - 450

* Range results from use of two different assumptions regarding discharges/TDS concentration factors from gasification facilities. See text for further explanation.

approximately one million acre-feet, with ten coal gasification plants located upstream in the Sarpy, Armells, and Rosebud Creek drainages. For CDP II the flow is projected to be depleted by approximately 450 thousand acre-feet with three coal gasification plants located upstream. No change is projected for the Yellowstone at Miles City under CDP I. All of these TDS projections are made for a location upstream of the confluence with the Tongue River and therefore do not include any effects due to discharges into the Tongue.

On the average, only a slight increase in the TDS concentration at Miles City is projected under both CDP's II and III. An annual average increase of less than 1 percent is projected for CDP II and an increase of up to about 3 percent for CDP III.

c. Tongue River at Miles City, Montana

Table IV-A.2-2 shows the results of the TDS projections (year 2000) for the Tongue River at Miles City. These projections show the largest increases in TDS for all the rivers analyzed in the Region. The projections for CDP I indicate the effect of reduced flow (by approximately 60 thousand acre-feet per year) from a new Tongue River Reservoir and discharges from three 1025 MW power plants. Under CDP II there is no new reservoir constructed on the Tongue, but three coal gasification plants and three 1025 MW power plants are located within the Basin. Five gasification plants and three power plants are projected for the Basin for CDP III, year 2000. For both Scenarios II and III the water required for coal conversion is supplied by aqueducts from the Bighorn and Yellowstone Rivers. The projected average annual percentage increase in TDS for CDPs I, II and III are respectively 19 percent, 19 to 35 percent, and 30 to 57 percent.

TDS projections for low flow conditions which occurred in 1966 (approximately a recurrence of once every seven years) show a greater increase in TDS concentration. Table IV-A.2-3 shows the results of these low flow projections. Under CDP II and flow conditions which occurred in 1966, the Tongue River at Miles City is projected to have, in 2000, an annual TDS concentration from 880 mg/l to 1120 mg/l, an increase of 36 to 73 percent over the annual average TDS concentration of 647 mg/l recorded for 1966.

d. Powder River at Moorhead, Montana

Table IV-A.2-4 shows the results of the TDS projections for the Powder River at Moorhead. Unlike the Tongue River projections, the TDS calculations made for the Powder River are not for a location near the mouth. But it is assumed that all coal-conversion plant wastes are discharged upstream of Moorhead. Although it appears that several plants are located in the Little Powder River Basin, which flows into the Powder below Moorhead, these discharges were accounted for at Moorhead by addition to the system, which should not appreciably alter the results, since the flows at the different locations should not be significantly different.

TABLE IV-A.2-2

Total Dissolved Solids Projections for Tongue River at Miles City, Montana

Month	Calculated Average TDS (mg/1)	Projected TDS Concentration (mg/1)		
		CDP I Year 2000	CDP II Year 2000	CDP III Year 2000
January	723	846	838 - 980	910 - 1141
February	682	815	801 - 924	873 - 1075
March	487	552	573 - 613	628 - 696
April	610	688	686 - 738	737 - 826
May	612	630	669 - 707	710 - 775
June	325	364	374 - 386	407 - 426
July	425	472	541 - 586	609 - 688
August	468	775	752 - 939	863 - 1169
September	508	756	710 - 838	807 - 1022
October	689	806	786 - 883	849 - 1011
November	689	794	778 - 866	838 - 984
December	818	936	891 - 1025	949 - 1165
Annual Average (rounded)	586	700	700 - 790	760 - 920

TABLE IV-A.2-3

Total Dissolved Solids Projections
for
Los Flow Conditions (1966), Tongue River at Miles City, Montaha

Month	1966 Average TDS (mg/1)	Projected TDS Concentration (mg/1)		
		CDP I Year 2000	CDP II Year 2000	CDP III Year 2000
January	819	939	910 - 1097	977 - 1258
February	759	909	884 - 1084	961 - 1262
March	568	690	705 - 803	782 - 941
April	724	912	862 - 1055	942 - 1233
May	653	640	792 - 933	872 - 1091
June	559	575	726 - 850	814 - 1012
July	552	694	806 - 1030	910 - 1249
August	589	966	855 - 1133	958 - 1364
September	669	977	862 - 1102	954 - 1309
October	498	563	579 - 618	631 - 695
November	627	699	725 - 805	788 - 917
December	751	870	851 - 997	920 - 1143
Annual Average (rounded)	647	790	800 - 960	880 - 1120

TABLE IV-A.2-4

Total Dissolved Solids Projections
for
Powder River at Moorhead, Montana

Month	Calculated Average TDS (mg/l)	Projected TDS Concentration (mg/l)		
		CDP I Year 2000	CDP II Year 2000	CDP III Year 2000
January	1300	1707	1252 - 1419	1119 - 1586
February	1050	1295	1068 - 1198	1023 - 1320
March	1050	1112	719 - 1116	1037 - 1165
April	1500	1611	1446 - 1542	1362 - 1565
May	1450	1500	1423 - 1476	1373 - 1453
June	950	972	959 - 982	955 - 1014
July	1600	1753	1527 - 1639	1413 - 1657
August	2650	3790	2145 - 2501	1713 - 2366
September	2150	3350	1788 - 2109	1436 - 2039
October	1750	2280	1607 - 1783	1355 - 1800
November	1700	2131	1563 - 1743	1341 - 1771
December	1550	2005	1445 - 1618	1246 - 1686
Annual Average (rounded)	1558	1960	1420 - 1590	1280 - 1770

Under CDP I, one 1200 MW power plant discharges to the Powder River and is supplied water through the construction of "Moorhead Reservoir". For CDP II the same 1200 MW power plant is accompanied by two coal gasification plants, all of which are supplied with water by an aqueduct from the Bighorn River. The concurrent construction of "Pumpkin Reservoir" on the Powder River is utilized to supply water to one gasification plant south of Gillette, Wyoming (outside the Powder River Basin) in CDP II. "Moorhead Reservoir" remains for CDP III a total of seven coal gasification plants and the one power plant are located within the Basin and all utilize water pumped from the Bighorn River.

The analysis of the Powder River is complicated by these changes in the water supply systems (reservoirs and aqueducts) designated for each coal development scenario. For CDPs I and II the flow in the Powder River is modified (and reduced by withdrawals) by the construction of Moorhead and Pumpkin Reservoirs. This development tends to result in higher TDS projections in CDPs I and II than in CDP III, where no reservoirs are projected. The analysis is further complicated by the fact that the Powder presently has high TDS concentrations and the water supplied from the Bighorn River after use and under the initial concentrating factor assumptions, i.e., a concentration factor of 1.5 for coal gasification plants, acts as dilution water when discharged into the Powder. The aqueduct supplying water from the Bighorn River is designed for use in CDPs II and III and therefore tends to lower TDS projections for these scenarios. The overall result is that the highest TDS projection is made for CDP I with an annual average increase of approximately 25 percent over the calculated historic average of 1558 mg/l.

e. Yellowstone River at Sidney, Montana

Table IV-A.2-5 shows the results of the TDS projections for the Yellowstone River at Sidney. These projections account for all water resource development and coal-conversion plants within the Yellowstone Basin. The Yellowstone River has substantial dilution capacity and therefore there is less change in TDS than in the previously discussed Tongue and Powder tributaries.

On the average the annual increase projected in TDS concentration by 2000 is 10 mg/l for CDP I and 40 to 60 mg/l for CDP III. This represents a potential percentage increase of 2 percent to 13 percent from the historic average concentration of 470 mg/l.

TDS projections for low flow conditions which occurred in 1966 (approximately a recurrence of once every ten years) result in projection of a greater increase in TDS at Sidney. Table IV-A.2-6 gives the results of TDS projections for these low flow conditions in the Yellowstone River at Sidney. On an annual percentage basis these projections represent respectively a 3 percent, 3 to 5 percent, and 11 to 17 percent TDS increase for CDPs I, II and III.

TABLE IV-A.2-5

Total Dissolved Solids Projections for Yellowstone River at Sidney, Montana

Month	Calculated Average TDS (mg/l)	Projected TDS Concentration (mg/l)		
		CDP I Year 2000	CDP II Year 2000	CDP III Year 2000
January	553	565	569 - 581	612 - 653
February	464	474	482 - 491	527 - 558
March	516	521	525 - 530	546 - 653
April	594	601	602 - 609	624 - 646
May	419	423	426 - 429	444 - 453
June	290	291	294 - 295	303 - 306
July	323	326	330 - 331	344 - 349
August	425	441	441 - 448	480 - 503
September	439	456	456 - 465	502 - 530
October	505	516	517 - 525	549 - 574
November	526	537	539 - 547	571 - 600
December	583	596	596 - 608	633 - 673
Annual Average (rounded)	470	480	480 - 490	510 - 530

TABLE IV-A.2-6

Total Dissolved Solids Projections for Low Flow Conditions (1966), Yellowstone River at Sidney, Montana

Month	1966 Average TDS (mg/l)	Projected TDS Concentration (mg/l)		
		CDP I Year 2000	CDP II Year 2000	CDP III Year 2000
January	639	649	649 - 771	679 - 718
February	580	590	593 - 605	630 - 667
March	467	473	477 - 483	503 - 520
April	549	563	564 - 576	606 - 645
May	360	365	371 - 375	400 - 412
June	207	210	218 - 219	241 - 246
July	316	319	333 - 338	372 - 388
August	480	512	505 - 519	581 - 641
September	547	576	569 - 586	642 - 714
October	471	478	479 - 483	499 - 512
November	529	541	542 - 552	577 - 607
December	701	711	708 - 719	730 - 765
Annual Average (rounded)	487	500	500 - 510	540 - 570

f. Missouri River at Bismarck, North Dakota

Analysis of future salinity (TDS) levels in Western Dakota Tributaries was not performed for this report. Data on present TDS levels are available for the Knife, Heart, Cannonball, Belle Fourche, and Cheyenne Rivers so that a first order analysis could be performed. A prediction of the average annual TDS concentration at Bismarck on the Missouri River is made to determine the cumulative effect of most of the coal and associated development.

The TDS projections for the Missouri River at Bismarck are made using two different annual average flow conditions of 15.5 million acre-feet per year and 13.6 million acre-feet per year. The 15.5 million acre-feet corresponds to the approximate flow resulting from coal development only and the 13.6 million acre-feet includes other projected depletions, primarily the Garrison Unit diversion.

The estimation of additional salts added to the Missouri River from the coal development in the Yellowstone River Basin is made using the TDS projections for the Yellowstone River at Sidney. The impact of power and gasification plants located in the Knife and Heart River Basins and along the Missouri River in North Dakota is included in this analysis. An estimation of the average annual TDS concentration is made, instead of monthly, because of the difficulty in determining the time lag involved in transport of dissolved solids from Sidney, through Garrison Reservoir, to Bismarck.

Table IV-A.2-7 gives the results of these TDS projections for CDPs II and III. No discernible change in the TDS concentration at Bismarck was projected for CDP I.

g. Summary of Results

A summary of the TDS projections is given in Tables IV-A.2-8 and IV-A.2-9. Table IV-A.2-8 summarizes the annual percentage increases in TDS projected for each scenario-location combination. For all locations, except for the Powder River at Moorhead, there is an increase in TDS concentration with increased coal-energy development. The analysis of the Powder River is complicated by the various changes in the water supply systems (reservoirs and aqueducts) designated for each coal development scenario (see earlier discussion of the Powder River projections).

The TDS projections indicate that of the rivers analyzed the Tongue River has the greatest potential for being impacted by discharges from coal conversion facilities. Projected increases in TDS range from 19 percent for CDP I, 19 to 25 percent for CDP II and 30 to 57 percent for CDP III. This potential TDS increase is in part due to the relative low dilution capacity (flow) in the Tongue River. Also the Tongue River historically has low TDS concentrations compared

TABLE IV-A.2-7

TDS Projections for the Missouri River at Bismarck, North Dakota

Approximate Annual Flow	Calculated Average TDS	CDP II, Year 2000 Projected TDS		CDP III, Year 2000 Projected TDS	
Million Acre-Feet Per Year	(mg/l)	mg/l	% Increase	mg/l	% Increase
15.5	436	445 - 449	2 - 3	465 - 477	7 - 9
13.6	436	461 - 467	6 - 7	482 - 495	11 - 14

TABLE IV-A.2-8

Annual Average Percentage Increase in Total Dissolved Solids Resulting from Coal & Associated Development, Year 2000

Location \ CDP	I	II	III
Yellowstone River at Miles City, Montana	0%	0.5%	0.5 to 3%
Tongue River at Miles City, Montana	19%	19 to 35%	30 to 57%
Powder River at Moorhead, Montana	26%	-9* to 2%	-18* to 14%
Yellowstone River at Sidney, Montana	2%	2 to 4%	8 to 13%
Missouri River at Bismarck, North Dakota	0%	2 to 7%	7 to 14%

* The negative sign indicates a decrease instead of an increase.

TABLE IV-A.2-9

August-September Average Total Dissolved Solids Concentration (mg/1)

CDP Location	I	II	III
Yellowstone River at Miles City, Montana	No change	416 - 419	420 - 430
Tongue River at Miles City, Montana	766	731 - 889	835 - 1095
Powder River at Moorhead, Montana	3570	1967 - 2305	1575 - 2203
Yellowstone River at Sidney, Montana	449	449 - 457	491 - 517

* Only the annual average TDS concentration is projected for the Missouri River at Bismarck, North Dakota; therefore no results are given for the August-September average.

to the other Yellowstone and Missouri River Tributaries analyzed, and therefore discharges with high TDS concentrations will result in a greater change in the Tongue River than in the Powder, Knife and Heart Rivers.

Table IV-A.2-9 gives the August-September average TDS concentration projected for each location, except the Missouri River, and for all three CDPs. These projections are averages and therefore do not represent the highest possible concentration. Average TDS concentrations for these two months are given because of the importance of water for agricultural uses during this portion of the year.

The Environmental Protection Agency has proposed total dissolved solids water quality criteria for irrigation and livestock watering[1]. Quoting the proposed criteria, "The maximum acceptable concentration of total dissolved solids in irrigation waters are 2,000 to 5,000 mg/l for tolerant plants in permeable soils or 500 to 1000 mg/l for sensitive crops", and "The maximum acceptable salinity level for livestock drinking water is 3000 mg/l of soluble salts". Examining Table IV-A.2-9 indicates that only for the Powder River do the TDS projections exceed irrigation and livestock watering criteria. At all other locations the criteria for irrigation waters for sensitive crops are approached or exceeded in all three scenarios. Since the impact of dissolved solids on irrigated crops and livestock is not as easily determined as the criteria suggest (see Appendix I) the important point is that some of these projected values can cause problems depending upon the local conditions.

This analysis of TDS impacts is a first look at water quality changes resulting from Northern Great Plains coal-energy development. In performing this analysis the emphasis has been placed on determining river basin and regional impacts. Local impacts such as the effect of a surface mine or new irrigation project on a certain river have not been analyzed. Local impact analysis must be performed when the nature and location are known for a proposed development.

The TDS projections shown in the previous pages are the result of choosing methods which can make these projections given the available data. Certain assumptions are inherent in these modeling methods, and further assumptions about future coal related activity are made to facilitate the analysis.

New activities within the Region, other than coal gasification and power generation plants, are assumed to not have an effect on the rivers' TDS concentration. But, the expansion of such land-related activities as mining, drilling, irrigation and construction can have an adverse impact on this water quality parameter. Increased usage of water for industrial and domestic needs would also concentrate dissolved solids. In any effort to upgrade the results shown here these activities must be considered, along with more realistic water use and discharge estimates for coal-conversion facilities.

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[1] Proposed Criteria for Water Quality - Volume I, EPA, October, 1973, Irrigation - page 48, Livestock - page 76.

IV-B Analysis of Dissolved Oxygen Impact at Selected Locations Within the Northern Great Plains Region

This section analyzes the potential depletion of dissolved oxygen (DO) in streams and rivers receiving effluents from municipal plants in the NGP. The impact of sewage treatment plant discharges on waters of the Region can be quantified given sufficient data on the character of the stream and the discharge. Data requirements and assumptions used in performing this DO analysis are discussed. A step-by-step procedure is outlined for making calculations of DO deficits resulting from municipal waste discharges. Finally, the potential dissolved oxygen impact at three selected municipalities in the NGP is analyzed for a given set of assumptions.

IV-B.1 Objectives and Rationale of the Analysis

a. Objectives

There are two equally important objectives of this analysis. The first is to make an initial estimate of the impact on dissolved oxygen concentration resulting from discharges of municipal waste into waters of the Region. In performing this analysis, emphasis is placed on determining the impact at locations where substantial population growth might be expected and/or for rivers in which the flow rate might be substantially decreased by NGP coal development. The DO impact or deficit is estimated for only a few municipalities for which the population and stream flow conditions are substantially different.

The second objective is to show that an analysis of this kind can be performed, resulting in useful information which can be applied to the state and local planning processes. Because of the sparsity of appropriate data, it is important that careful attention be paid to the sensitivity of the results to various inputs. If the values of certain estimated inputs are appropriately varied, giving a range of results, then these results can be applied with some degree of confidence to the planning process.

b. Data Considerations

In order to perform a dissolved oxygen analysis, data are required to characterize both the stream or river being discharged into and the effluent which is discharged. The data needs for each of these areas depends upon the complexity of the local situation. Situations which can be considered complex are; proximate multiple discharges, high diurnal variation in DO due to algal or benthal demand, non-point or dispersed sources of oxygen demanding material, and extreme longitudinal variations in stream flow and shape characteristics. These situations require that data be collected specifically for the dissolved oxygen analysis. The data used in this analysis were not collected specifically for it and therefore the above complications are assumed not to be present. This assumption is considered reasonable for the locations analyzed.

To a degree these situations which tend to make the analysis more difficult can be factored into a first cut analysis. For example, a safety factor of 0.5 to 1.0 mg/l DO deficit can be subtracted from the result to account for diurnal and dispersed dissolved oxygen demands. Small variations in stream flow and shape can be considered by varying these characteristics over a "feasible" range of values, giving a range of results as mentioned earlier. There is no substitute for good and plentiful data, but in its absence an initial analysis can be made which will serve as a starting point for further investigation and decision-making.

c. Assumptions

The assumptions made to facilitate this analysis are listed and discussed below.

1. The Streeter-Phelps equation is used to determine the dissolved oxygen deficit which assumes that the system can be approximated as being steady state with constant spacial characteristics along each reach. The use of this equation is not new and has been used with varying degrees of success at many locations.

2. The municipal wastes were treated by secondary treatment resulting in an average five-day biochemical oxygen demand (BOD) of not more than 45 milligrams per liter. This number is consistent with EPA's secondary treatment standard requiring the five-day BOD monthly average not to exceed 30 mg/l and the weekly average not to exceed 45 mg/l. The ultimate BOD is calculated to be 1.5 times the five-day BOD.

3. The ammonia concentration in the effluent was assumed to be 15 mg/l. Therefore, the nitrogenous oxygen demand is calculated to be 68 mg/l. This ammonia concentration is typical for a mechanical secondary treatment plant but might be high for lagoon treatment in the summer and low in the winter.

4. A daily per capita waste flow of 125 gallons was assumed for this analysis. This figure represents the typical situation in many communities of the Region.

5. Uncertainties in the analysis about various oxygen demands are incorporated to some degree in a "background" or natural quality as a constant DO deficit of 0.5 mg/l. This constant deficit covers such oxygen related phenomia as; algal photosynthesis and respiration, benthal oxygen demand, distributed BOD sources, and an initial DO deficit.

6. The dissolved oxygen concentration was assumed to be at saturation prior to municipal waste discharge at the locations analyzed. What limited DO data are available for the Region indicates that the concentrations are often near saturation and there are no significant waste discharges immediately upstream of the locations analyzed.

7. The dissolved oxygen deficit in the effluent was assumed to have a negligible effect on the DO concentration in the stream. Assuming effluent DO deficits of 2.0 mg/l and 3.0 mg/l do not affect the DO response of the stream when the discharge is less than half the stream flow. No situations were analyzed where the discharge makes up more than half the stream flow.

IV-B.2 Results of Analysis for Three Selected Municipalities

The dissolved oxygen analysis is made for two municipalities located along the Yellowstone River, Billings and Miles City, and for one municipality in the Tongue River drainage basin, Sheridan, Wyoming. These municipalities are chosen because of the availability of USGS data and because these sites represent a range of flow and population impacts which might be representative of any Northern Great Plains coal-energy development.

a. Yellowstone River at Billings, Montana

Billings, Montana is now in the process of building a 22 million gallon per day (MGD) capacity secondary treatment plant. Consequently, the dissolved oxygen analysis is performed assuming a discharge of 22 MGD or 34 cubic feet per second (cfs) with an ultimate oxygen demand of 136 mg/l as stated in the previous assumptions for secondary treatment. Since flow in the Yellowstone River passing Billings is not projected to be changed by coal development, the 7-day, 10-year low flow for August, 2750 cfs, is analyzed. The mean water temperature for August is calculated to be 22°C, resulting in a DO saturation concentration of 7.8 mg/l, with elevation taken into consideration (See Chapter I for calculation methodology). The proposed Montana state standard at this location is 5.0 mg/l.

After complete mixing of the effluent with the River's flow, the ultimate oxygen demand is calculated to be 1.7 mg/l. Using this figure as the ultimate oxygen demand, L_o, in the Streeter-Phelps equation and the worst case "feasible values" for depth, velocity, K_a, K_d, the critical deficit is calculated to be approximately 0.1 mg/l assuming no "background" deficit. This calculation indicates the treated waste load is very much within the assimilative capacity of the River. Assuming a "background" deficit of 0.5 mg/l caused by other less discernable sources and a mixing zone of one-half the stream flow, the critical deficit is recalculated to be 0.7 mg/l. Again, this deficit indicates that the waste load is within the assimilative capacity of the River.

The population which would cause assumed waste load is difficult to determine because of the substantial amount of waste contributed by industrial plants in the city. A 22 MGD treatment plant can serve 176,000 people assuming a per capita flow rate of 125 gallons per day. Assuming that 15% of the total waste flow is attributable to non-domestic, non-commercial sources, the service population is then reduced to less than 150,000.

Table IV-B.2-1 shows population estimates made by the socio-economic work group for the NGPRP. These estimates are given in Columns 1 and 2. Columns 3 through 6 are population estimates for Billings and Miles City, assuming that their percentage of the 1970

TABLE IV-B.2-1

Population Projections for Montana Economic Impact Area*, Billings, and Miles City, Montana

CDP	II	III	II	III	II	III
Area / Year	Montana Economic Impact Area		Billings (70% of M.E.I.A. Projections)		Miles City (10% of M.E.I.A. Projections)	
1980	130,531	142,121	91,371	99,484	13,053	14,212
1985	146,801	182,803	102,760	127,960	14,680	18,280
2000	175,682	250,894	122,977	175,623	17,568	25,089

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* See "Projections of Economic Development Associated with Coal-Related Activity in Montana", Paul E. Polzin, University of Montana.

population for the Montana economic impact area remains the same in the future. These estimates for Billings indicate that the 22 MGD plant will probably meet future needs with the possible exception of CDP III for the year 2000.

b. Yellowstone River at Miles City, Montana

The Yellowstone River at Miles City is assumed to be flow impacted by Northern Great Plains coal-energy development. Therefore, the DO analysis will be performed using the Instream Needs Flows. The Instream Needs Flow for the Yellowstone at Miles City is 5,100 cfs for August. Assume, for the moment, a population of 25,000 as shown in Table IV-B.2-1 for the year 2000 and CDP III. Under the assumptions stated for this analysis, this population would create an effluent discharge of approximately 5 cfs resulting in an ultimate oxygen demand of 0.13 mg/l after mixing with the river. At this point it is obvious that there is no need to continue the analysis, since such a low ultimate demand could not significantly deplete the dissolved oxygen concentration. Therefore, with secondary treatment as defined for this analysis, and reasonably good mixing of the discharge effluent, the DO concentration in the Yellowstone should not be substantially changed as a result of this Miles City effluent. This analysis assumes complete mixing; therefore, does not address local DO problems resulting from poor mixing.

c. Goose Creek at Sheridan, Wyoming

Goose Creek is a tributary of the Tongue River and is located near the headwaters of the River. Sheridan, Wyoming, with a 1970 population of 10,856, discharges its municipal wastes into Goose Creek. This stream is not expected to be flow impacted by coal-energy development itself, and consequently the historical 7-day, 10-year low flow of 11 cfs will be used for analysis. A population of 10,000 is estimated to discharge treated wastes at a rate of 2 cfs. This discharge, after secondary treatment and complete mixing with the stream, would result in an ultimate oxygen demand of 18 mg/l. The mean water temperature of Goose Creek at Sheridan is estimated to be 22°C during August, resulting in a DO saturation concentration of 7.5 mg/l after correction for elevation. The Wyoming dissolved oxygen standard for this tributary of the Tongue River is 6.0 mg/l. Assuming an average stream depth of 0.8 feet and an average velocity of one foot per second, the critical DO deficit is calculated to be 0.8 mg/l at 2.5 miles downstream of the discharge. This deficit would result in a DO concentration at this downstream point of 6.7 mg/l, which indicates that the present population, even with secondary treatment, can significantly reduce the dissolved oxygen concentration. If "background" oxygen demands are present to cause an additional 0.5 mg/l deficit, the critical DO concentration would be 6.2 mg/l, or very near the state standard.

To determine the dissolved oxygen impact of population growth in Sheridan due to coal-energy development, an analysis is performed initially assuming a population of 20,000. The results of this analysis are given in Table IV-B.2-2. As shown, the "feasible range" of stream depth is 0.3 feet to 0.8 feet, for which 0.5 feet is estimated as the mean value. The data strongly indicated an average stream velocity of approximately one foot per second and therefore the velocity was not varied. The coefficients K_a and K_d are varied according to the relationship defining them by stream depth and velocity. The results indicate that for secondary treatment and the assumed stream conditions a population between 14,000 and 23,000 would cause the DO concentration in Goose Creek to drop to the state standard of 6.0 mg/l. While these results represent a substantial range in population, they can be compared with population projections to obtain information on whether a problem may result from coal-related growth.

In a special report[1] submitted for this analysis, the population of Sheridan was projected for the years 1985 and 2000 for each development CDP. Table IV-B.2-3 summarizes these projections. As shown, no population increase is projected for 1985, CDPs I and II, and for 2000, CDP I. For the year 2000 and CDP III development, the city's population is projected to almost double.

These population projections, when compared with the results in Table IV-B.2-2, indicate a potential dissolved oxygen problem in Goose Creek for two unique development situations. A DO problem could result from CDP III development during the years between 1985 and 2000 or for coal-energy development between CDPs II and III around the year 2000. If either of these situations were realized, the city of Sheridan would likely need to upgrade their municipal waste treatment efficiencies beyond that of secondary treatment. Of course, these results are highly dependent upon the validity of the coal development scenarios and the population projections based on them. If coal-energy development is more intense around the Sheridan area than the scenarios project, then the environmental impacts will likewise be greater.

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[1] "Population Projection and Estimated Methodology: Subbasins of the Powder and Tongue River Drainages in Wyoming", 1974, Cecil Cundy, Research Assistant, Division of Business and Economic Research, University of Wyoming.

TABLE IV-B.2-2

Dissolved Oxygen Analysis for Goose Creek

Below Sheridan, Wyoming

Trial Population	Ultimate Oxygen Demand After Mixing, Lo (mg/1)	Average Stream Depth (ft)	Average Stream Velocity (ft/sec)	Ka (/day)	Kd (/day)	DO Saturation Concen-tration (mg/1)	Critical DO Deficit Including 0.5 mg/1 Background (mg/1)	Critical DO Concen-tration (mg/1)	Population at which DO Standard is Just Met
20,000	36.0	0.8	1.0	19.0	1.2	7.5	2.1	5.4	14,286
		0.5	1.0	38.0	1.5	7.5	1.7	5.9	17,647
		0.3	1.0	82.0	2.0	7.5	1.3	6.2	23,077

TABLE IV-B.2-3

Population Projections for Sheridan, Wyoming Resulting from Coal-Energy Development

CDP Year	I	II	III
1985	10,856	10,856	14,817
2000	10,856	14,366	20,693

IV-B.3 Summary of Dissolved Oxygen Analysis

In examining the dissolved oxygen impact resulting from municipal waste discharges, this analysis has given a first estimate of the expected impact for three municipalities, in addition to describing the procedure which can be used to make a similar analysis at other locations. The results from the analysis made for Billings, Miles City, and Sheridan indicate that secondary treatment of wastes often meets the receiving waters dissolved oxygen standard. Only for Sheridan did the analysis indicate a potential DO problem as a result of the possible population growth projected from coal-energy development. The potential problem for Sheridan is primarily caused by its location along Goose Creek, a low flowing stream during late summer and winter. The possibility exists that secondary treatment will not be adequate for other potential growth areas located along similar streams and that limited discharge or tertiary treatment will be required to meet the state water quality standards.

In this analysis of DO impacts, an important assumption has been made which should be emphasized again, which is that secondary treatment as defined by EPA is assumed for all municipal waste discharges. Since the secondary treatment standard is required for all municipalities by July of 1977, this assumption is reasonable. But the realities of financing the upgrading of existing treatment facilities may cause a lag in implementation of this standard. This situation is especially true for small rapidly growing communities which require substantial revenue to provide secondary treatment for future populations but lack the economic base upon which to generate the need dollars. The existence of such communities will most likely be fostered by rapid coal-energy development. If so, state and federal governments must recognize this problem at an early stage and formulate plans to deal with the local needs. Otherwise, the pollution of streams and rivers will be more drastic than revealed by this analysis.

IV-C Qualitative Discussion / Water Quality Impacts

It is not possible to quantify all changes in water quality that would (or might) occur if coal is developed in the Northern Great Plains. The preceding sections showed quantifiable effects of development on dissolved oxygen and total dissolved solids for three patterns of possible future development in the Northern Great Plains. Other impacts are not as easily quantifiable because the analytical tools are not available; because data to make reasonable assumptions from are not available; or because so many questions remain as to how development would occur that reasonable assumptions are not yet possible. As the following discussion will show, the effects of coal development on water quality could be significant.

The simplest format for discussion of water quality impacts is to relate the impacts to the cause. Certain water quality impacts can be expected if only mining of NGP coal were to occur, with all of the coal being exported out of the Northern Great Plains. Greater impacts can be expected if coal conversion facilities (such as power plants and coal gasification plants) are also located in the NGP. Finally, even greater water quality impacts can be expected as coal energy development promotes an influx of people and small industry needed to provide goods and services to the expanding economy of the region. Of course, it must be recognized that each of the above developments can occur at different levels, as is shown by the three coal development profiles chosen for analysis by the NGPRP.

IV C.1 "Mining Only" Impacts

In Chapter I it was shown that runoff can be expected to increase from areas disturbed by surface operations such as mining. The exact amount of sediment that will accompany the increased runoff is not easily estimated. However, in many disturbed areas the increased sediment loading to streams can have important impacts on the aquatic ecosystem. Sediment may settle in slow flow areas impacting benthic communities; increased turbidity in the waters has a negative impact on both aesthetics and fisheries; increased water treatment (meaning increased costs) becomes necessary for other water users as sediment increases; and the increased loss of top soil (and moisture) can make revegetation of disturbed areas more difficult.

In general, the impact from one mine on a stream or river probably will, in itself, be significant only locally, if at all. However, while only four mines are planned for the Tongue River Basin in the CDP I scenario, thirty-two mines are planned for the Tongue River Basin in the CDP III forecast. The same type of rapidly growing impact can be seen on other streams such as the Belle Fourche, Powder and Knife Rivers as the number of mines for the low and extensive scenarios range from three to eight, two to eighteen, and three to fifteen respectively.

In addition to storm runoff eroding the disturbed surface and carrying sediment directly to a stream, many mines will find that their active pit fills regularly from both runoff and ground water infiltration. It is then frequently necessary to pump water from the pit. Pit dewatering is covered under the NPDES permit program, and strict effluent limits should minimize the sediment impacts from such operations. One method of control of sediment from runoff is to construct large "no discharge" ponds. However, the subsequent reduced stream flow resulting from "no discharge" impoundments may create problems.

Dissolved solids are also present in runoff from disturbed areas. Previous analysis of potential increases in total dissolved solids neglected any input from mine runoff, however. Therefore, the earlier TDS analyses (Section IV-A) appear to yield conservative estimates of future impacts, if all other assumptions are valid. Again, one mine on a stream will probably have only minor impact on TDS. Many mines on a stream will probably have a measurable impact. Significant increases in TDS will affect present agricultural uses, as well as the aquatic ecosystem.

Runoff, in addition to increasing suspended and dissolved solids, can also result in increased concentrations of trace elements in streams. Many elements are present in small concentrations in both coal and overburden. During mining operations as the surface is disturbed and greater (and different) amounts of soils are exposed to water, the concentrations of trace elements in the neighboring surface waters can be expected to increase. At this time it is not possible to predict: 1) which elements are present in large concentrations; 2) which elements will preferentially leach into the waters; 3) how much the concentrations of the various elements will increase; or (perhaps the most important) 4) what the environmental effects are of increased concentrations of certain trace elements in surface waters.

Again, direct surface runoff does not represent the total input to a trace element problem. Spoil piles from surface mines can collect water which can leach additional trace elements prior to entering ground water (or surface waters as a result of a larger storm). Pit dewatering can also result in increased concentrations of selected trace elements.

The potential ground water problems associated with mining are addressed in Chapter V. Potential ground water problems include quantity and quality changes and involve principally shallow ground water.

A discussion of the water quality impacts of mines in the NGP must include impacts associated with the export of coal. Construction of additional roads and railroads will result in some increase in land disturbance, providing an increased potential for erosion and siltation of nearby streams. Construction of slurry pipe lines would, in addition to causing at least temporary surface disturbance impacts, cause additional impacts by consumptive water use. In such a method of transport, however, water quality problems would also surface at the end use point.

IV-C.2 Coal Conversion Impacts

Coal conversion facilities (presently steam electric generating plants with gasification plants to follow) are presently being built in the NGP, and more are planned. All of the potential impacts associated with mining still apply to these facilities, however, additional water quality degradation is possible.

Perhaps the greatest concern and most serious potential problems related to water "requirements" of coal conversion facilities. Power plants require water for process use, for condenser cooling water, and for domestic uses within the plant as discussed in Chapter 1. Gasification plants have similar process, cooling, and domestic uses for water. The Water Work Group has assumed a water "need" of 19,000 acre feet per year for a 1,000 MW power plant and 30,000 acre feet per year for a 250 x 10^6 scf/day gasification plant. All of this "needed" water is not consumptively used at the conversion facilities, so an effluent can be expected from these facilities. It is likely that power plants and gasification plants will be built that utilize much less water and have no effluent. Water quality impacts for such plants would be much less. However, for preliminary analyses in NGPRP reports, the figures given above were used.

The greatest potential for detriment to water quality impact associated with on-site conversion facilities in the NGP remains consumptive use of water. The water "needed" for these plants will come from the streams and rivers in the NGP. Many of these streams already have critical low flow periods. If the flow in streams is reduced below certain levels, serious impacts on the aquatic ecosystem follow. If water for development comes from switching water currently used for agriculture to industrial use, the impacts switch from water quality impacts to social and economic impacts. Such a switch would also affect water quality, but most likely to a lesser extent. A common assumption is that water can be removed from a stream to a certain point with little or no adverse impact. However, if flow is reduced below the "instream need", serious problems result. (At this time not enough is known about the water requirements of aquatic ecosystems in the NGP. Therefore, the amount of water "available" for use other than by the aquatic ecosystem can only be speculated.)

Preliminary indications from the Water Work Group are that "instream needs", as defined by the Instream Needs Subgroup, will be met for all streams in the NGP for all three CDPs under evaluation by the NGPRP. Different CDPs will result in flow depletions to different streams. In general, lower levels of development will likely utilize new storage on streams near the development, such as the Tongue and Powder Rivers. Conversely, larger scale developments approaching CDP III will most likely utilize water from a few large reservoirs on major rivers such as the Bighorn and Yellowstone, with aqueducts to development areas.

Reduced flows in streams can cause a variety of water quality problems. (Chapter III refers to biological impacts that can be expected from lower flows, such as reduced spawning areas, reduced riparian vegetation, disrupted wild life, waterfowl patterns, etc.) Lower flows also can result in higher summer temperatures and lower winter temperatures. Such temperature changes can seriously impact aquatic ecosystems, fish in particular. Lower stream flows generally mean lower velocities. Lower velocities will allow greater amounts of sediment to settle on stream bottoms and can harm benthic communities and reduce fish habitat. Lower stream flows, for a given load of any pollutant, particularly one such as total dissolved solids, result in higher concentrations.

Massive development of mine mouth conversion plants could result in a need for significant additional storage capacity on certain NGP streams. Water quality problems associated with reservoir impoundments on presently free flowing streams are covered later in this chapter (Section IV-D) and in Appendix IV.

Ground water could conceivably be a source for additional water for conversion facilities. Both shallow ground water and deep ground water represent potential water sources. However, ground water is also a depletable resource. While there is a recharge of ground water, recharge rates are basically constant. Therefore, if ground water is used above the recharge rate, depletion will occur.

Some water quality impact can be expected from water transportation systems. Mine mouth conversion facilities, particularly with large scale development, will require water transmission. In addition to increased surface disturbance during construction of these aqueducts and canals, other environmental impacts are possible. The exact impact of many such transbasin diversions is not known. Additional research is needed to assess the impact of such alternative systems.

As mentioned above, coal conversion facilities utilizing water in the quantities assumed by the NGPRP can expect to have effluents. Because all facilities discharging liquid effluents must have NPDES permits, overall water quality impact from point source discharges should be minimized. However, some pollutants such as TDS are considered expensive to treat and, therefore, frequently are not covered by the best practicable treatment requirements of NPDES permits. Effluents will also include trace elements in low, but sometimes significant, concentrations. The impact of low level increases of potentially toxic trace elements is not known. Potential for toxic impacts on a chronic (long term, low level exposure) level is great. Coal gasification effluents are difficult to predict. While treatment would be required, effluents could still contain dissolved solids, trace elements, organic pollutants, oils and greases, and certain nutrients.

The construction of coal conversion stations can also cause water quality impacts. A typical coal gasification plant will cover the better part of two sections of land. Surface disturbance and the associated runoff problems will result. Both suspended and dissolved solids can be expected to be impacted. Other impacts are possible, depending on construction practices, location, construction materials, etc.

IV-C.3 "People" Impacts

In order to develop the mines, in order to design and build conversion facilities, in order to run the mines and conversion facilities, and in order to provide support and services for all types of development, many people will be needed. In addition to the obvious social, cultural, and economic aspects associated with large scale influxes of people, many potentially serious water quality impacts are possible.

Additional people will have requirements for additional water. Towns need water for domestic purposes, irrigation, fire control, and other miscellaneous uses. These water requirements will compete with other water requirements for the existing water, creating additional problems in meeting instream needs flows. These impacts on stream flow have been discussed.

Perhaps the greatest potential detrimental water quality problem associated with an influx of large numbers of people is from the discharge of inadequately treated sewage. Chapter I discusses the particular problems associated with domestic sewage. Past experience has shown that rapidly growing areas usually do not have adequate sewage treatment facilities. Treatment of sanitary wastes is usually the responsibility of a municipal government or sanitation district. Funds for their operation come from user fees, while funds for construction usually come from the sale of bonds offered by the town or district. Inevitably, as rapid growth occurs, there is a lag in the system and approval of funds for construction of additional facilities takes several years. Design and construction of new facilities also takes several years. During the interim time, the town usually discharges untreated or poorly treates wastes. This causes dissolved oxygen problems, nutrient problems, ammonia problems, and bacteria problems in the receiving water. If only a few communities experience boom growth, problems of this type will be minimized. Conversely, if many communities experience boom growth, significant water quality problems can be expected in many locations.

Municipal discharges of sanitary wastes are also controlled by the NPDES permit program. Therefore, the long-term water quality problems associated with these wastes should be minimized. However, certain other factors should be mentioned. Small towns discharging to large streams generally do not cause large-scale water quality problems. Large towns discharging to small streams generally can (and do) cause significant water quality problems. Secondary treatment is usually sufficient to mitigate most water quality problems. However, large discharges into small streams, or into large streams made small through depletions, will require additional treatment at significantly additional costs to prevent water quality problems. Costs of energy development thus include such costs as additional treatment required by cities as receiving stream flow is reduced for industrial development.

Water quality will also be impacted in growing areas because of construction activities. The construction of houses, businesses, roads, schools, etc., will all disturb surface areas creating problems during storm runoff periods. Suspended and dissolved solids will increase in affected streams. Depending on the surface and near surface composition of the geologic materials, other parameters may also be affected, such as certain trace elements.

An influx of people for mines and coal conversion facilities inevitably will lead to increased development of secondary industries. Again, ignoring obvious social, cultural, and economic impacts of such additional development, water quality impacts are possible and probable. These industries would also have water "requirements" which would also compete for the limited available water. Many would have effluents which would affect water quality. Finally, these developments would bring more people and their related water quality impacts.

Additional people in the NGP will place increased pressure on the recreational opportunities that are available. This additional pressure on recreational facilities is significant, both in the increased demand itself and because coal development may reduce the amount of available recreational areas. Development and its water requirements will directly compete with recreational use for water in the streams. Construction of storage, while creating a reservoir usable for recreation, could affect present recreational uses of the area.

Finally, increased people will require increased food. This could require, for the NGP, additional irrigation of the arid lands. This increased demand for irrigation water will again create increased competition for waters in the area, with the associated water quality impacts of reduced flows.

While the above discussion of impacts is only qualitatively presented and full of qualifications and possibilities, it does show that significant water quality problems are possible. It further shows that the greater the level of coal development, the greater the potential for serious water quality impacts. But most important, this discussion shows areas which must be further addressed by local, state, and Federal governments and industry, in order to understand and deal with water quality problems which can result from hurried and ill-planned energy resource development.

IV-D Potential Effects of Proposed Impoundments on Water Quality and Fisheries in the Northern Great Plains

Few reservoirs currently exist in the area of the Northern Great Plains proposed for coal strip mining. The construction of reservoirs in this region has been suggested to serve as a water source for the developing coal industries. Up to the present time, no attempt has been made to assess the potential effect of the proposed reservoirs upon the water quality and aquatic organisms of the streams to be impounded.

A literature review was conducted to determine possible changes in water quality and biota that might be expected from impoundment of streams in the Northern Great Plains. Possible factors that may affect water quality and living organisms in a reservoir are illustrated in Figure IV-D-1. A discussion of how these factors regulate reservoir water quality is presented in Appendix IV. Data relating to the factors that were found for various sampling sites in the Northern Great Plains were used to approximate expected changes in water quality and fisheries in the proposed reservoirs.

Expected water quality changes in the proposed reservoirs must be discussed for each individual reservoir site. Discussion of six potential reservoirs in the Powder River Basin, Wyoming, is presented here. The vastness of the area included in the Northern Great Plains precluded a discussion of each reservoir site at the present time.

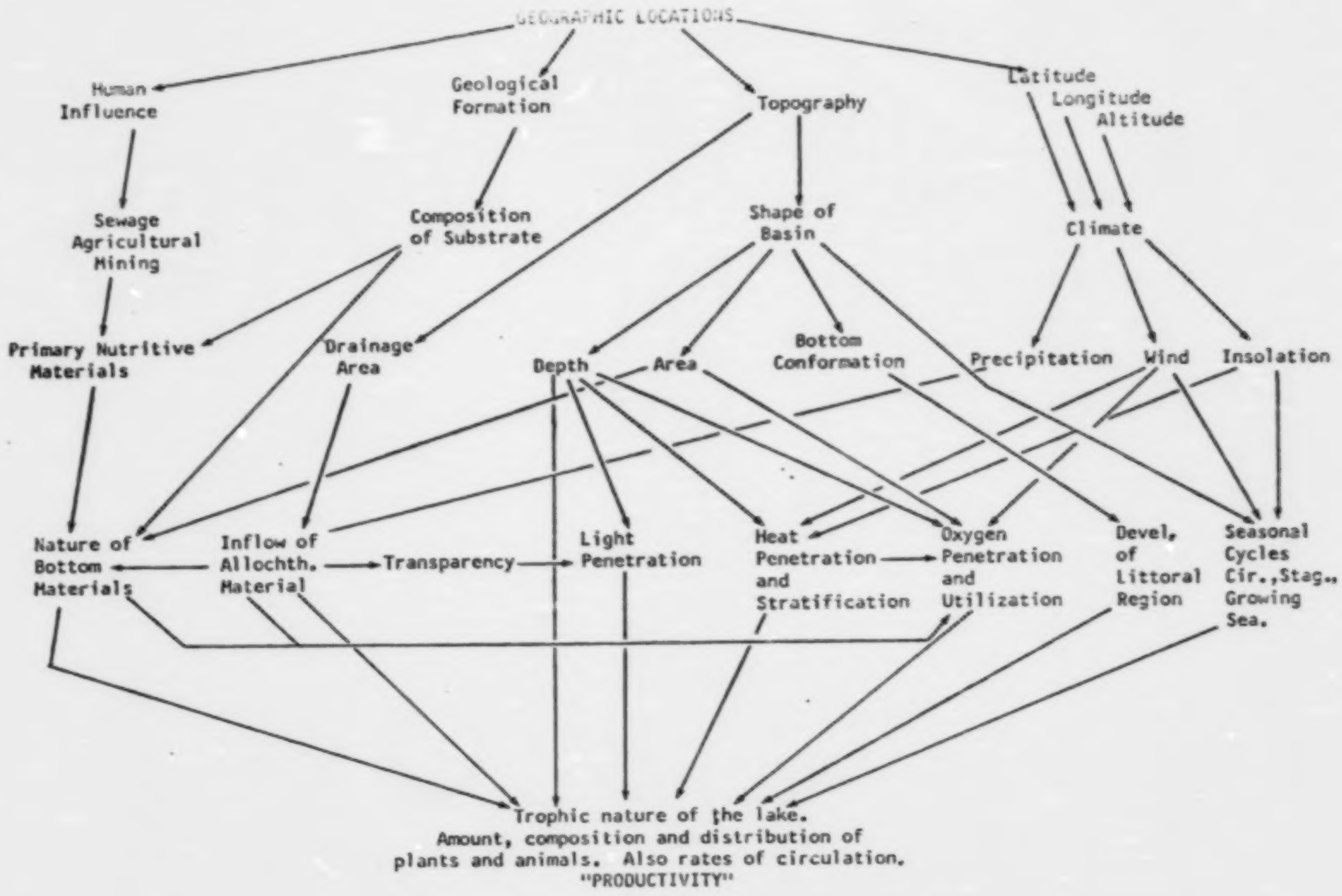
GEOGRAPHIC LOCATIONS
Human Influence
Geological Formation
Topography
Latitude
Longitude
Altitude
Sewage Agricultural Mining
Composition of Substrate
Shape of Basin
Climate
Primary Nutritive Materials
Drainage Area
Depth
Area
Bottom Conformation
Precipitation
Wind
Insolation
Nature of Bottom Materials
Inflow of Allochth. Material
Transparency
Light Penetration
Heat Penetration and Stratification
Oxygen Penetration and Utilization
Devel, of Littoral Region
Seasonal Cycles Cir.,Stag., Growing Sea.
Trophic nature of the lake.
Amount, composition and distribution of plants and animals. Also rates of circulation.
"PRODUCTIVITY"

Figure IV-D-1 A diagram showing contributions toward a lake productivity from factors inside and outside the water. (After Prescott, 1963 and Rawson, 1940), (page 421)

IV-D.1

Reservoir Water Chemistry in the Powder River Basin

The potential reservoir sites studied in the Powder River Basin and hydrological parameters are listed in Table IV-D.1-1 and locations noted on Figure IV-D.1-1. The potential reservoir sites are located within two soil groups. Hole-in-the-Wall is located over mountain soils, and the remaining sites, located in the plains, are underlain by prairie soild. The proposed reservoirs will fall into two main categories in water chemistry, based on location and soil types. "Hole-in-the-Wall" will have a low dissolved mineral content, and the prairie reservoirs will have a high dissolved mineral content. This assumption can be further substantiated by comparison of water quality records of the Powder River Basin (Table IV-D.1-2).

The proposed reservoirs on streams tributary to the Powder will have water chemistry typifying their basin geology. Hembree, et. al.[1] reported limited water quality data for Crazy Woman Creek and Clear Creek. They found TDS and sulfates to average 1380 ppm and 860 ppm in Crazy Woman Creek near Buffalo, and 1170 ppm and 705 ppm in Clear Creek near Arvada.

No data could be found for Box Elder Creek. Lake DeSmet, Wyoming, however, is located approximately five miles from the potential Box Elder Reservoir site. Water chemistry in this lake might be expected to be very similar to that in the proposed Box Elder Reservoir. Hembree, et. al.[1] found TDS and sulfates of Lake DeSmet to be 816 ppm and 386 ppm, respectively.

Some approximations of water chemistry in the proposed reservoirs can be made using the above data. It must be remembered that some of the data are old and limited, and may not reflect the current conditions in the river basins. The following broad generalizations, however, are felt to be valid. The dissolved mineral content of the proposed reservoirs on the main stem of the Powder will increase from the headwaters to downstream areas. Hole-in-the-Wall will be the lowest in dissolved mineral content and Arvada the highest. Crazy Woman and Clear Creek Reservoirs should have water chemistry similar to Pumpkin and Arvada. Box Elder will probably have a mineral content intermediate between Hole-in-the-Wall and the other prairie reservoirs. Water in all of the reservoirs, with the exception of Hole-in-the-Wall, will be of the sulfate-bicarbonate type. Mineral (nutrient) content of the proposed reservoirs will probably not be limiting to algal growth.

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[1] Hembree, C. H., B. R. Colby, H. S. Swenson, and J. R. Davis, 1952. Sedimentation and Chemical Quality of Water in the Powder River Drainage Basin, Wyoming and Montana. U.S. Geological Survey Circular No. 170. 92 pp.

Table IV-D.1-1

POTENTIAL STORAGE SITES IN THE POWDER RIVER BASIN, WYOMING
(From U.S. Dept. Interior, Bur. Reclamation Data)

Name of Storage Site	Stream and Location	Approximate Site Capacity (Acre - Feet) At Maximum	For Flood Space	For Active Storage	Average Annual Inflow	Critical Year Inflow	Estimated Average Annual Sediment	Water Surface Acres At Normal Pool	At Minimum Pool
Box Elder	Box Elder Creek near Ucross, Wyoming	54,500	*	*	*	*	*	*	*
Lower Clear Creek	Clear Creek near Powder River, Wyoming Confluence	602,000	175,000	*	*	*	*	*	*
Arvada	Powder River near Arvada, Wyoming	1,255,000	250,000	275,000	196,000	136,000	*	18,000	13,900
Lower Crazy Woman	Crazy Woman Creek near Powder River, Wyoming Confluence	450,000	153,000	*	*	*	*	*	*
Pumpkin	Powder River near Pumpkin Creek, Wyoming Confluence	1,000,000	304,000	*	*	*	*	*	*
Hole-in-the-Wall	Middle Fork Powder River, upstream Kaycee, Wyoming	55,000	*	45,000	*	*	*	*	*

After: Anon. 1973. Potential Storage Sites. U.S. Department of the Interior, Bureau of Reclamation. 1 page.

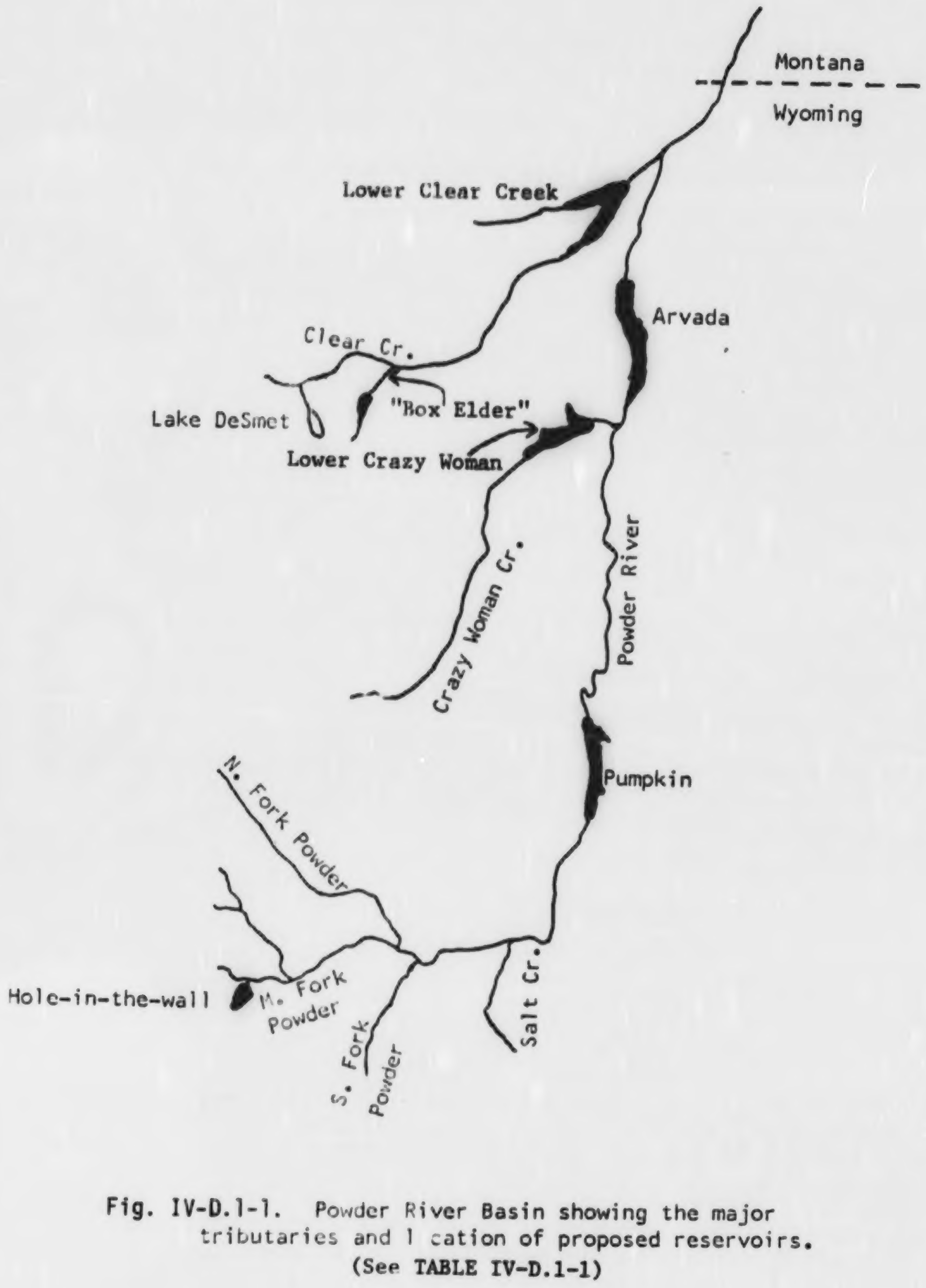
Montana
Wyoming
Lower Clear Creek
Arvada
Clear Cr.
"Box Elder"
Lake DeSmet
Lower Crazy Woman
Crazy Woman Cr.
Powder River
Pumpkin
N. Fork Powder
Hole-in-the-wall
M. Fork Powder
S. Fork Powder
Salt Cr.

Fig. IV-D.1-1. Powder River Basin showing the major tributaries and location of proposed reservoirs. (See TABLE IV-D.1-1)

Table IV-D.1-2

Mean Water quality values for selected parameters on the main stem of the Powder River and the Middle Fork of the Powder River.[1, 2]

Station	TDS mg/l	SO4= mg/l	Cl- mg/l	-HCO mg/l
Barnum, Wyo. *	158	5.6	4.0	
Kaycee, Wyo.	872	412	54.5	212
Sussex, Wyo.	1452	739	244	278
Moorehead, Mt.	1552	637	97.5	102

* Barnum is located on the Middle Fork of the Powder near Hole-in-the-Wall site. Barnum data are averages from a four-day sampling period in 1949.

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1. Anon. 1974. Water Quality Data Summary of the Yellowstone, Bighorn, Tongue, and Powder River Basins. Technical Investigations Branch, Surveillance and Analysis Division, Environmental Protection Agency, Denver, Colorado. 53 pages. Mimeo.
2. Hembree, C. H., B. R. Colby, H. S. Swenson, and J. R. Davis, 1952. Sedimentation and Chemical Quality of Water in the Powder River Drainage Basin, Wyoming and Montana. U.S. Geological Survey Circular No. 170. 92 pages.

IV-D.2 Factors Affecting Powder River Reservoirs

The proposed reservoirs will have two major longitudinal axes. Pumpkin, Arvada, and Box Elder will lie generally in a north-south direction. Hole-in-the-Wall, Clear Creek, and Crazy Woman will lie in a southwest to northeast direction.

Prevailing wind directions in central Wyoming from fall to the spring months (October - March) are in a general southwest to northeast direction with an average velocity of 16 mph[1]. During the spring and summer months (April - September), the prevailing winds tend to be more from a westerly direction, with average velocities of approximately 12 mph. These annual wind cycles would tend to promote better wind circulation in the reservoirs with longitudinal axes closely paralleling the prevailing wind directions. The reservoirs lying in a north-south direction would be less affected by wind circulation. If water depth is sufficient to permit stratification, it will be more likely to develop in the proposed Pumpkin, Arvada and Box Elder Reservoirs.

Evaporation loss from the reservoirs in Wyoming may have a pronounced effect on the water chemistry. Mean annual lake evaporation for central Wyoming ranges from 40 to 44 inches[1]. Limited data presented in Table IV-D.1-2 allow evaporative losses to be estimated for only the Arvada Reservoir. With 18,000 surface acres exposed to evaporative conditions at normal pool, the Arvada Reservoir could experience an evaporation loss of approximately 33% (64,800 acre feet) of its average annual inflow of 196,000 acre feet. This evaporative loss and low summer flows may tend to increase the dissolved solids content of the reservoir. The same problem could be expected to affect the other plains reservoirs.

Turbidity of the Powder River Basin

High turbidity of the Powder River drainage was noted by Hembree, et. al.[2]. These researchers collected sediment discharge data on the Powder River near Arvada from April 4, 1946, to September 30, 1950. During this time, they estimated sediment accumulation in a reservoir (if one were constructed at Arvada) to be 21,420 acre feet. Hembree, et. al. also presented limiting data showing that sediment discharges on Clear Creek and Crazy Woman Creek were similar to the Powder main stem. These authors also recorded the presence of easily erodible shales, clays, and sand stones in the upper terraces of the Powder River flood plain. This type of formulation is susceptible to easy shoreline erosion of a reservoir, caused by wave action. This type of erosion-sedimentation process could significantly affect the

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1. Anon. 1968. Climatic Atlas of the United States. U.S. Department of the Interior. Environmental Sciences Service Administration. Environmental Data Service. Washington, D.C. 80 pp.
2. Hembree, C. H., B. R. Colby, H. S. Swenson, and J. R. Davis, 1952. Sedimentation and Chemical Quality of Water in the Powder River Drainage Basin, Wyoming and Montana. U.S. Geological Survey Circular No. 170. 92 pp.

proposed reservoirs in the Powder River Basin. A large amount of sediment derived from shoreline erosion would seriously affect any fish spawning activities near the headwaters of the reservoir. The turbid conditions might also limit algal and benthic organism production.

Biological Conditions in the Powder River Basin

Periphyton and plankton data from the Powder River Basin were not found in the literature. Fisheries inventories conducted by Wyoming Fish and Game Commission personnel delineated fishery distribution within the Powder River drainage, and also furnished some limited benthic macroinverterbrate distributional data. All of the data that follow were obtained from reports of the Wyoming Game and Fish Commission[1, 2].

The stream reach proposed for the Hole-in-the-Wall Reservoir supports an excellent trout fishery. Wyoming Fish and Game officials classed this area as a Class 2 trout stream, meaning very good trout waters of statewide importance. A reservoir in the area will have relatively low productivity as a result of the high elevation and low mineral content.

No fishery data were found for Box Elder Creek. But Lake DeSmet is located only five miles from this small stream. Therefore fishery conditions in the proposed reservoir might be expected to be similar to Lake DeSmet. Lake DeSmet supports populations of rainbow and brown trout, yellow perch, rock bass, black crappie, carp, white sucker, longnose sucker, and mountain suckers. Midges are reported to be the major benthic organisms. Fish productivity is reported as being good. Lake DeSmet also has served as a source for spring spawn of rainbow trout since 1935.

Lower Clear Creek is reported incapable of supporting a sport fishery at the present time. Wyoming Fish and Game personnel stocked the area of Clear Creek from Buffalo to Ucross with brown trout and channel catfish. Subsequent investigations failed to show survival of either species. This lack of survival was attributed to high water temperatures, insufficient spawning grounds, food, shelter and silty conditions. Non-game fish were reported to be abundant in lower Clear Creek. The species recorded in this area were: carp, northern redhorse, goldeye, flathead chubs, longnose dace, creek chubs, fatheat minnows, white suckers, longnose suckers, and mountain suckers. Macroinvertebrates found in the area were: beetles (Coleoptera), flies (Diptera), mayflies (Ephemeroptera), snails (Gastropoda), water bugs (Hemiptera), and caddis flies (Trichoptera).

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1. Anon. 1962. A Fisheries Survey of Lakes and Streams in the Powder River. Drainage, 1961-1962. Wyoming Game and Fish Commission. Fish. Tech. Report No. 10. 90 pp.
2. Anon. 1971. Wyoming Stream Classification. Wyoming Fish and Game Commission. Fish Division. (map)

The section of the Powder River that might be affected by a Pumpkin or Arvada reservoir was reported to be an unproductive sport fishery. The only sport fish found in this stream reach are black bullheads and stonecats. Sport fish were limited in this area by extreme flow variations and high turbid spring runoff. Non-game species found inhabiting pools in the river included fathead chubs, carp, goldeye, northern redhorse, fathead minnows, longnose dace, white sucker, longnose sucker, and mountain sucker.

Lower Crazy Woman Creek was also unproductive as a sport fishery. Non-game fish reported in this stream included: carp, white suckers, plains flathead chubs, and goldeye. Bottom conditions were mainly silt, sand, and fine gravel. Macroinvertebrates were limited to flies (Diptera) and mayflies (Ephemeroptera).

IV-E Impacts for Alternative Sites of Coal Conversion Facilities

The previous discussions of water quality impacts associated with coal development all are based on development of the type outlined in the three coal development profiles developed for impact analysis by the NGPRP. Alternate siting of conversion facilities, near large bodies of water, as opposed to mine mouth or load center location, has not yet been addressed by the NGPRP. For analysis of potential impacts to be more complete, there is a definite need to assess the physical and ecological impacts of building conversion facilities utilizing once through cooling on large water bodies in the NGP, such as the Missouri River.

To accomplish this, the Water Quality Subgroup has developed a project in conjunction with a consortium of electric generating utilities to evaluate the size of areas affected by large thermal discharges associated with hypothetical power plants located on the Missouri River at various locations.

Five sites were chosen for analysis. The five sites chosen are:

1. Site No. 1 - located on the east side of Oahe Reservoir in Township 131N, Range 79W, approximately 18 miles southwest of Linton, North Dakota.

2. Site No. 2 - located on open water between Oahe Reservoir and Garrison Dam in Township 143N, Range 82W, on the south side of the Missouri River, approximately three miles east of the town of Washburn, North Dakota.

3. Site No. 3 - located on the south shore of Lake Sakakawea in Township 146N, Range 88W, approximately 15 miles north, northwest of Beulah, North Dakota.

4. Site No. 4 - located on the west shore of the northerly arm of Garrison Reservoir in Township 151N, Range 92W, approximately 14 miles southwest of Hankins, North Dakota, and eight miles south, southeast of New Town, North Dakota.

5. Site No. 5 - located on the west shore of the west leg of Fort Peck Reservoir in Township 25N, Range 40E, approximately 20 miles south, southeast of Glasgow, Montana.

Hypothetical generating units of 1000, 1500, 2000, 3000, and 4000 megawatt sizes were located at these locations. The size of the thermal plume will be evaluated for several different discharge configurations. The configurations studied at each location included:

1. Open channels, both perpendicular and at angles to stream flow.
2. Submerged single port discharge.
3. Submerged multiple port discharge.

A heat rate suitable for the coal most likely utilized at such a facility (sub-bituminous or lignite) was assumed for each plant. A twenty (20) degree Farenheit temperature rise in the condenser will be assumed. The evaluation was done with computer models appropriate for the circumstances in each case. In addition to presenting the size of the plume for each of the above circumstances at each site, the project briefly discusses future information needs.

The report is included as Appendix V. It is concluded, based upon the computer modelling, that additional biological studies are warranted.

CHAPTER V

QUALITY OF GROUND WATER

Though ground water is not used extensively throughout the Northern Great Plains in comparison to surface water, there is sufficient reliance on the shallow ground waters by select individuals, communities, and other activities to make the potential impact of resource development on these waters important. Numerous samples of ground water have been chemically assayed through the twentieth century. However, no comprehensive regional analysis of ground water quality has been published, or to our knowledge, initiated. Ground water quality is not expected to change substantially as a result of coal development unless the quality of waters that feed the aquifer changes or if substantial drilling activity either interconnects aquifers of poor quality with those of acceptable quality, allows infiltration of contaminated waters into the aquifers, or allows increased leaching of minerals into the aquifer. But many of the samples collected over the years and reviewed here were collected from wells whose condition was not well known and for which geohydrologic data were not available. Thus samples attributed to one aquifer may in fact have been from shallower aquifers which were leaking through deteriorated casing into the well. Certain chemical analyses may not be particularly accurate which then decreases the precision when averaging separate analyses for one aquifer. This lack of accuracy relates to variations between laboratories through the years, lack of duplicate assays and duplicate samples, and lack of emphasis on drawing correlations between certain aquifers and water quality.

Most of the existing chemical data have been obtained from samples collected from the shallower aquifers of the Northern Great Plains. These aquifers include alluvium or relatively recent alluvial and terrace deposits. These have been utilized to a high degree for domestic and agricultural purposes since they require only shallow drilling. As is shown in the State-by-State reiterations of data in the following sections, the quality of water drawn from alluvial and terrace aquifers in the Northern Great Plains is highly variable. For example, concentrations of total dissolved solids range from 382 ppm to 27,708 ppm (parts per million) in the tabulated data. The recommended concentration for water used for domestic purposes is 500 ppm.

The high degree of variability of quality of alluvial ground water is related to (1) the varied occurrences of alluvial material in proximity to different bedrock formations, (2) the relatively short distances of travel from areas of recharge to areas of withdrawals and the increasing trend of surface waters that recharge the alluvial aquifers to become contaminated by man's activities such as agricultural irrigation and urban uses of water. In other words, the quality of ground water within the alluvial aquifers tends to respond more quickly to contamination of surface and near surface waters than do waters in deeper bedrock (consolidated material) aquifers.

Yet water flowing through most of the bedrock aquifers tends also to deteriorate in quality as it progresses down-gradient through the formation. This deterioration is caused by weathering of minerals contained in the formations. The weathering or "leaching" continues to take place as the water moves through the formation. It may be hypothesized that the aquifers have not experienced leaching to the degree experienced by older aquifers in more humid climates and thus that the potential for leaching remains greater in the semi arid West. Alluvial aquifers are also subjected to evaporation which concentrates the salts. Water quality is often reported as decreasing down-gradient in the aquifers of the Northern Great Plains. An exception to this down-gradient decrease in quality is thought to occur as water passes through the coal aquifers of the area. In these cases, the coal seams may act as a "filter" and quality in terms of dissolved gases or organics could improve, though there does not appear to be published data indicating such a change in water quality.

It is notable that a high degree of variation takes place in water quality in any one aquifer. In fact, it becomes somewhat academic to derive averages for the concentrations of numerous elements in water from one aquifer because of this high degree of variation. Since much of the data comes from the very shallow aquifers (alluvium, Fort Union and Hell Creek Formations) which in turn are highly dissected or eroded, the varied recharge and travel characteristics within a named aquifer may partially explain the variations. That is, these shallow aquifers are quite discontinuous such that areas of recharge change and distances from areas of recharge to areas of withdrawals also vary. These factors, compounded by lateral changes in lithology, make it exceptionally difficult to describe the region-wide ground water quality in terms of averages.

Grover[1] summarized water quality for various aquifers in the Northern Great Plains. The average, maximum, and minimum values calculated from his report are reproduced below in Table V-1. Alluvial aquifers appear to contain hard water caused by high concentrations of calcium and magnesium. Almost all waters from alluvial aquifers are bicarbonate as opposed to carbonate. Waters from shallow wells in the Fort Union and Lance Formations are similarly hard. Water from deeper strata in the two formations or buried Fort Union and Lance are often softer, have larger, yet still minor carbonate content, and may contain higher sulphate concentrations.

Waters from the Fox Hills, Judith River, or Eagle Sandstone (the Montana Group) show a range in quality similar to that of the aforementioned Fort Union/Lance aquifer. Chlorides were reported by Grover

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[1] Grover, Nathan C., 1925, "Contributions to the Hydrology of the United States", U.S. Geological Survey Water Supply Paper 560.

TABLE V-1

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers in The Northern Great Plains

(data in parts per million unless otherwise noted)

After: Grover, 1925

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as $Ca\ CO_3$	F	B
Alluvium (superficial clay, sand, gravel)	MAX	3660			500	201	880	883	1600	472		1972		
	AVE	1027			124	53	140	412	382	58		574		
	MIN	223			15	9	4	95	12	1		88		
Fort Union Formations (sandstone, shale, coal)	MAX	3735			336	215	920	2152	2440	306		1722		
	AVE	1080			54	41	286	666	316	33		295		
	MIN	274			4	1	8	63	2.6	1		15		
Lance Formation (sandstone, shale, coal)	MAX	2911			110	71	957	1674	1594	533		516		
	AVE	1381			21	13	470	789	379	72		108		
	MIN	170			3.8	0.8	8	155	1	2		14		
Fox Hills and Judith River Formations (Montana Group)	MAX	8726			523	285	2438	1691	5609	1048		1907		
	AVE	1742			82	54	457	562	676	80		460		
	MIN	336			3	1.7	16	44	5.9	1		18		
Dakota and Associated Sandstones	MAX	4799			204	72	1710	1402	1989	1832		772		
	AVE	1988			60	16	629	662	542	355		150		
	MIN	174			5	1.2	3	49	2	2		17		

(In order of increasing depth)

to be higher to the east in the Montana Group. The data in Table V-1 also show a tendency of these waters to contain higher concentrations of sulphate (SO_4).

The so-called Colorado Group has as its principal aquifer the Dakota Sandstone. The data for the Dakota Sandstone as presented in Table V-1 are somewhat biased in that many of the samples analyzed came from "deep" wells drilled for oil. These data characterize the Dakota as relatively soft and relatively high in chloride content. However, the waters of the Dakota of the western Northern Great Plains are not as mineralized. The quality of water varies with depth through the sandstone.

Additional published data are summarized for the various states of the Northern Great Plains in the ensuing tables. As may be observed, data from Montana and North Dakota represent the shallow aquifers and data from South Dakota begin to address the aquifers of intermediate depth. Data for the ground waters of Wyoming have not been treated.

Each report referenced treats small (geographical) areas within one state. Data have been presented only for those water-bearing strata that are, at present, regarded as "useable" aquifers. The data have also been presented in terms of the maximum average (arithmetic), and the minimum value. This presentation was used to condense the numerous analyses provided by some of the references. The averaging method may not be appropriate, however, due to the wide variation in concentrations of the elements in samples from the same geologic strata.

Montana

The general geology of eastern Montana is indicated by the stratigraphic correlation chart reproduced as Figure V-A-1. Ground water is found in all major divisions of the stratigraphic section, from Paleozoic to Cenozoic rocks. Interest in ground water supplies is generally directed to the very shallow alluvial aquifers, the Fort Union (Tongue River Member) Formations of the Cenozoic Era, the deeper Hell Creek, Fox Hills, Dakota, Lakota, and, where present, Chugwater Formations of the Mesozoic, and the still deeper Tensleep and Madison "Formations" of the Paleozoic. Also important are the young alluvial and stream terrace materials that lay close to the surface drainage routes in Southeastern Montana. Supplies from these alluvial deposits are quite important in the Yellowstone River watershed since they extend along the majority of the Yellowstone River and along many of the major tributaries of the Yellowstone[1].

In general terms, the shallow aquifers of eastern Montana yield water that is of moderately good quality. The deeper bedrock aquifers of eastern Montana tend to contain more highly mineralized waters.

Alluvial aquifer waters of the Yellowstone River and its tributaries are generally reported as hard sodium-sulfate types with relatively high concentration of total dissolved solids (ca. 1000 ppm). However, review of the data in Tables V-A-1 and V-A-2 shows that such a characterization is difficult.

Five additional tables summarizing water quality in the relatively shallow aquifers of Montana are included here. Wherever five or more wells entering the same aquifer were chemically assayed, arithmetic means and maximum-minimum values were derived from the referenced report and listed in the Tables. Table V-A-1 contains data gathered from wells in the northwestern portion of the Yellowstone drainage. Table V-A-2 presents data collected along the Yellowstone River, Table V-A-3 contains data for southeastern Montana, Table V-A-4 addresses the northern portion of the Powder River Valley, and Table V-A-5 looks at the intermediate area in Rosebud County. Aquifers are listed in order of increasing depth.

Table V-A-6 presents more recent data collected by Moulder, et al[2] for the lower Little Bighorn River Valley. These data have been reproduced in their entirety to portray the variation in concentrations of various elements from one well to the next. In general, the waters are high in sodium, and are predominately sulphate waters.

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1. U.S. Geological Survey, 1963, "Mineral and Water Resources of Montana", Report of the U.S. Geological Survey & Montana Bureau of Mines and Geology to the Committee on Interior and Insular Affairs, U.S. Senate prepared at the request of Senator Lee Metcalf (Montana).
2. Moulder, E. A., M. F. Klug, D. A. Morris and F. A. Swenson, 1960, "Geology and Ground Water Resources of the Lower Little Bighorn River Valley, Big Horn County, Montana", with a section on "Chemical Quality of Water by R. A. Krieger, U.S. Geological Survey Water Supply Paper 1487.

Figure V-A-1

SEDIMENTARY FORMATIONS IN THE NORTHERN GREAT PLAINS *

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
		A. NORTHEASTERN MONTANA	
		Sources of data: Collier (1917); Jensen and Varnes (1964); Witkind (1959).	
Alluvium----------------	10±	Sand, gravel--------------------	Unconsolidated.
Glacial deposits--------	15±	Clay, silt, sand, gravel--------	Do.
Flaxville Formation-----	20±	Sand, gravel--------------------	Generally unconsolidated.
Fort Union Formation----	2,000±	Sandstone, siltstone, claystone-	Many thin lignite beds.
Hell Creek Formation----	250±	Claystone, siltstone, shale, sandstone.	
Fox Hills Sandstone-----	35-145	Claystone, siltstone, and sandstone at base overlain by massive sandstone.	
Bearpaw Shale-----------	800-1,140	Shale --------------------------	Many thin bentonite beds.
Judith River Formation--	400	Sandstone, claystone------------	
Claggett Shale----------	750	Shale---------------------------	
		B. BIG SNOWY MOUNTAINS, BULL MOUNTAINS BASIN, AND ADJACENT AREAS IN CENTRAL MONTANA	
		Sources of data: Foster (1956); Gardner (1950); Mallory (1972); Reeves (1931); Wolsey, Richards, and Lupton (1917).	
Alluvium----------------	10±	Sand, gravel, silt--------------	Unconsolidated.
Terrace deposit---------	10±	---do---------------------------	Do.
Fort Union Formation----	1,900	Shale, claystone, sandstone-----	Many coal beds.
Hell Creek Formation----	700-1,500	Sandstone, claystone, shale-----	Locally includes Lennep Sandstone at base.
Bearpaw Shale-----------	1,000+	Shale---------------------------	Some thin bentonite beds.
Judith River Formation--	200-400	Sandstone, siltstone, shale-----	
Claggett Shale----------	200-600	Shale---------------------------	Some thin bentonite beds.
Eagle Sandstone---------	200-525	Sandstone, shale----------------	
Colorado Shale----------	2,250	Shale, sandstone----------------	Many thin bentonite beds.
Kootenai Formation------	230-500	Shale, sandstone, limestone-----	Structure contour horizon (plate A-4).
Morrison Formation------	125-200	Shale, claystone, siltstone, sandstone.	
Ellis Group-------------	130-400	Limestone, shale, sandstone-----	Some gypsum.
Quadrant Formation------	0-50	Limestone, shale----------------	
Amsden Formation--------	100-200	Limestone, dolomite, shale------	
Big Snowy Group---------	800	Shale, sandstone----------------	
Madison Group-----------	1,600	Limestone-----------------------	
Snowy Range Formation---	425	Limestone, shale, siltstone-----	
Pilgrim Limestone-------	225	Limestone, shale----------------	
Wolsey and Park Shales--	300	Shale, limestone----------------	
Flathead Sandstone------	175	Sandstone, conglomerate---------	

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* After Keefer, 1974 Geology Work Group Report - NGPRP Draft.

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
C. BIGHORN MOUNTAINS, PRYOR MOUNTAINS, AND WESTERN POWDER RIVER BASIN			
Sources of data: Hose (1955); Keefer and Van Lieu (1966); Mallory (1972); Mapel (1959); Richards and Rogers (1951); Thom and others (1935); Denson, N. M., oral communication (1973); Sandberg, C. A., oral communication (1973).			
Alluvium----------------	10±	Sand, gravel, silt--------------	Unconsolidated.
Moncrief Conglomerate---	0-2,000	Conglomerate--------------------	
Arikaree Formation------	200±	Sandstone-----------------------	
White River Formation---	200±	Claystone, siltstone, conglomerate.	
Wasatch Formation-------	1,000+	Sandstone, shale, conglomerate--	Many coal beds.
Fort Union Formation----	2,000-4,000	Sandstone, siltstone, shale-----	Do.
Lava Formation Hell Creek Formation.	600-2,200	Sandstone, shale----------------	
Bearpaw Shale-----------	200-865	Shale, sandstone----------------	Some thin bentonite beds.
Judith River Formation--	250-350	Sandstone, shale----------------	Equivalent rocks termed Parkman Sandstone near Montana-Wyoming state line.
Claggett Shale----------	365-650	Shale---------------------------	
Cody Shale--------------	2,600-3,670	Shale, sandstone----------------	Some thin bentonite beds; includes Telegraph Creek Formation north of Montana-Wyoming state line.
Frontier Formation------	260-515	Sandstone, siltstone, shale-----	Some thin bentonite beds.
Mowry Shale-------------	335-525	Shale---------------------------	Several thin bentonite beds.
Thermopolis Shale-------	625	---do---------------------------	Several thin bentonite beds; basal part termed the Skull Creek Shale and Newcastle Sandstone in places south of Montana-Wyoming state line.
Cloverly Formation------	150-240	Sandstone, siltstone, claystone, shale.	Structure contour horizon (plate A-4).
Morrison Formation------	180-280	Shale, claystone, siltstone, sandstone.	
Sundance Formation------	285	Sandstone, shale, limestone-----	Sundance and underlying Gypsum Spring are termed the Ellis Group in places north of Montana-Wyoming state line.
Gypsum Spring Formation-	0-190	Shale, claystone, limestone-----	Some gypsum beds.
Chugwater Formation-----	355-810	Siltstone, shale, sandstone-----	
Goose Egg Formation-----	180-250	Shale, limestone, siltstone-----	Some gypsum beds.
Tensleep Sandstone------	0-420	Sandstone-----------------------	
Amsden Formation--------	200-300	Dolomite, limestone, sandstone, shale.	

C. BIGHORN MOUNTAINS, PRYOR MOUNTAINS, AND WESTERN POWDER RIVER BASIN--Continued

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
Madison Limestone-------	330-735	Limestone, dolomite-------------	
Jefferson Formation-----	0-255	Dolomite-----------------------	
Souris River Formation--	0-16	Limestone----------------------	
Beartooth Butte Formation.	0-140	Dolomite-----------------------	
Bighorn Dolomite--------	0-365	Dolomite, limestone-------------	
Gallatin and Gros Ventre Formations.	380-740	Shale, limestone, sandstone-----	
Flathead Sandstone------	215-345	Sandstone----------------------	

D. SOUTHWESTERN POWDER RIVER BASIN, CASPER ARCH, AND SOUTHEASTERN WIND RIVER BASIN

Sources of data: Crist and Lowry (1972); Hares (1946); Keefer (1972); Keefer and Van Lieu (1966); Mallory (1972); Olson (1954); Denson, N. M., oral communication (1973); Pipiringos, G. N., oral communication (1973).

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
Wind-blown sand---------	0-200	Sand---------------------------	Unconsolidated.
Ogallala Formation------	0-800	Siltstone, sandstone, conglomerate.	Unconsolidated in part.
Arikaree Formation------	0-1,000	Sandstone, limestone, tuff, conglomerate.	
White River Formation---	0-1,465	Sandstone, siltstone, conglomerate.	
Wagon Bed Formation-----	0-1,000	Mudstone, sandstone, conglomerate.	
Wind River Formation----	0-7,000	Claystone, shale, sandstone, conglomerate.	Present in Wind River Basin only; Wind River Formation equivalent in Powder River Basin is Wasatch Formation.
Fort Union Formation----	0-8,000	Sandstone, siltstone, claystone, shale.	Many coal beds in Powder River Basin.
Lance Formation---------	250-5,000	Sandstone, shale, siltstone-----	
Fox Hills Sandstone-----	0-1,000	Sandstone, shale---------------	
Lewis Shale-------------	200-600	Shale, sandstone---------------	
Mesaverde Formation-----	850-1,365	Sandstone, shale---------------	Some thin coal beds in Wind River Basin.
Cody Shale--------------	3,000-5,000	Shale, sandstone---------------	
Frontier Formation------	625-1,000	Sandstone, shale---------------	
Mowry Shale-------------	200-300	Shale--------------------------	Many bentonite beds.
Thermopolis Shale-------	100-200	---do--------------------------	Muddy Sandstone Member at top.
Cloverly Formation------	150-300	Sandstone, claystone, conglomerate.	
Morrison Formation------	150	Sandstone, claystone-----------	
Sundance Formation------	225-365	Shale, sandstone, siltstone, limestone.	

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
D. SOUTHWESTERN POWDER RIVER BASIN, CASPER ARCH, AND SOUTHEASTERN WIND RIVER BASIN--Continued			
Jelm Formation	120-395	Siltstone, sandstone	
Red Peak Formation	600-700	Shale, siltstone	
Goose Egg Formation	150-380	Shale, siltstone, limestone	Some gypsum beds.
Tensleep Sandstone	250-280	Sandstone	
Amsden Formation	140-200	Shale, sandstone, limestone	
Madison Limestone	250-325	Limestone	
Gallatin Limestone, Gros Ventre Formation, Flathead Sandstone.	200-800	Sandstone, shale	
E. LARAMIE MOUNTAINS AND SOUTHERN POWDER RIVER BASIN			
Sources of data: Denson and Bottinelly (1949); Denson and Horn (1972); Keefer and Van Lieu (1966); Mallory (1972); Olson (1954); Pipiringos, G. N., oral communication (1973).			
Ogallala Formation	0-400	Claystone, siltstone, sandstone, conglomerate.	
Arikaree Formation	600±	Sandstone, siltstone, limestone	
White River Formation	0-1,100	Siltstone, conglomerate, limestone.	
Wasatch Formation	0-1,800	Sandstone, siltstone, shale	Several coal beds.
Fort Union Formation	2,700-4,300	Sandstone, siltstone, claystone, shale.	Do.
Lance Formation	2,000-3,000	Shale, sandstone	Several thin coal beds in lower part.
Fox Hills Sandstone	500-800	Sandstone, shale	
Lewis Shale	400	Shale, sandstone	
Mesaverde Formation	900	Sandstone, shale	
Cody Shale	3,000-3,600	Shale, sandstone	
Frontier Formation	850-900	do	
Mowry Shale	200-300	Shale	Several thin bentonite beds.
Thermopolis Shale	75-250	Shale, sandstone	Includes Muddy Sandstone Member.
Cloverly Formation	65-320	Sandstone, claystone, shale, conglomerate.	
Morrison Formation	130-220	Claystone, shale, sandstone, limestone.	
Sundance Formation	220-480	Shale, sandstone, siltstone, limestone.	
Jelm Formation	0-45	Siltstone, sandstone	
Red Peak Formation	580-610	Siltstone, shale, sandstone	Some gypsum beds.
Goose Egg Formation	380-410	Shale, limestone, sandstone	Several gypsum beds.
Casper Formation	525	Sandstone, limestone	Hartville Formation (900-1,225') in southern Niobrara County.

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
E. LARAMIE MOUNTAINS AND SOUTHERN POWDER RIVER BASIN--Continued			
Madison Limestone-------	150-275	Limestone-----------------------	Guernsey Formation (140-260') in southern Niobrara County.
Flathead Sandstone------	0-90	Sandstone, conglomerate---------	
F. BLACK HILLS AND EASTERN POWDER RIVER BASIN			
Sources of data: Dobbin, Kramer, and Horn (1957); Mapel and Pillmore (1963); Robinson, Mapel, and Bergendahl (1964); U.S. Geological Survey and others (1964).			
White River Formation---	0-150	Sandstone, siltstone, claystone-	
Wasatch Formation-------	300±	Sandstone, shale----------------	Numerous coal beds.
Fort Union Formation----	1,200-2,270	---do---------------------------	Do.
Lance Formation, Hell Creek Formation.	500-2,500	---do---------------------------	
Fox Hills Sandstone-----	125-550	Sandstone, shale, siltstone-----	Colgate Sandstone Member at top.
Pierre Shale------------	945-3,100	Shale, claystone----------------	Several thin bentonite beds.
Niobrara Formation------	100-250	Shale---------------------------	Many thin bentonite beds.
Carlile Shale-----------	360-690	---do---------------------------	
Greenhorn Formation-----	70-370	Shale, limestone----------------	
Belle Fourche Shale-----	350-850	Shale---------------------------	
Mowry Shale-------------	180-230	---do---------------------------	Many thin bentonite beds.
Newcastle Sandstone-----	0-100	Sandstone, siltstone, shale, claystone.	Some thin coal and bentonite beds; equivalent to Muddy Sandstone Member of Thermopolis Shale.
Skull Creek Shale-------	160-270	Shale---------------------------	
Fall River Formation----	35-200	Sandstone, shale, siltstone-----	Structure contour horizon (plate A-4).
Lakota Formation--------	45-300	Sandstone, conglomerate, claystone.	Some thin coal beds.
Morrison Formation------	0-220	Claystone, shale, sandstone, limestone.	
Sundance Formation------	175-495	Shale, sandstone, siltstone, limestone.	
Gypsum Spring Formation-	0-125	Claystone, limestone------------	Abundant gypsum.
Spearfish Formation-----	450-825	Shale, siltstone, sandstone-----	Some gypsum beds.
Minnekahta Limestone----	30-50	Limestone-----------------------	
Opeche Formation--------	50-100	Sandstone, siltstone, shale-----	
Minnelusa Formation-----	650-1,000	Sandstone, limestone, dolomite--	Some gypsum and anhydrite.
Pahasapa Limestone------	500-600	Limestone-----------------------	
Englewood Limestone-----	50±	---do---------------------------	
Whitewood Dolomite------	50±	Dolomite------------------------	

Geologic unit	Thickness (feet)	Principal rock type(s)	Remarks
F. BLACK HILLS AND EASTERN POWDER RIVER BASIN--Continued			
Winnepeg Formation------	50-100	Sandstone, shale, siltstone-----	
Deadwood Formation------	300-400	Sandstone, limestone, shale, siltstone.	
G. SOUTHEASTERN MONTANA AND ADJACENT AREAS IN NORTH AND SOUTH DAKOTA			
Sources of data: Denson and Gill (1965); U.S. Geological Survey and others (1973).			
Glacial deposits--------	0-600	Sand, gravel, silt--------------	Unconsolidated.
Flaxville Formation-----	20-200	Sandstone, conglomerate, tuff, mudstone.	Largely unconsolidated.
Arikaree Formation------	200-360	Sandstone, limestone, shale, conglomerate.	
White River Formation---	250±	Sandstone, claystone, shale, siltstone, conglomerate.	Some bentonite beds.
Golden Valley Formation-	0-175	Sandstone, siltstone, claystone-	Some thin beds of lignite.
Fort Union Formation----	1,250-2,300	Sandstone, shale, siltstone-----	Many lignite beds.
Hell Creek Formation----	400-575	Claystone, sandstone------------	Some thin lignite beds.
Fox Hills Sandstone-----	25-300	Sandstone, shale----------------	
Pierre Shale------------	1,700-2,500	Claystone, shale----------------	Some thin bentonite beds.

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TABLE V-A-1

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers in Yellowstone and Treasure Counties, Montana

(data in parts per million unless otherwise noted)

After: Hall and Howard, 1929
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Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Alluvium and Terrace Materials	MAX	27,708	31	18	585	1129	8249	19[illegible]	17995	315	6.2	5980	-	-
	AVE	4,224	20	1.8	172	140	952	524	2448	66	2.8	1005	-	-
	MIN	382	6	T**	21	1	38	229	101	6	T	57	-	-
Fox Hills Formation	MAX	1348	20	0.81	92	80	248	488	622	9	8	526	-	-
	AVE	678	16	0.35	66	46	97	354	247	6	2	353	-	-
	MIN	278	10	T	49	22	6.4	227	47	3	T	228	-	-
Judith River Formation	MAX	8134	21	5.2	235	159	2438	1543	4871	636	5.1	1240	-	-
	AVE	2010	11.6	1.05	60	38	580	678	857	70	1.7	306	-	-
	MIN	640	5.5	T	3	1	94	314	5.2	5	T	16	-	-
Chugwater Formation	*	3687	19	6.2	611	172	200	235	2344	24	T	2230	-	-

* Individual Analysis

** T = trace

After: Hall, George M. and C. S. Howard, 1929, "Ground Water in Yellowstone and Treasure Counties, Montana", U.S. Geological Survey Water-Supply Paper 599.

TABLE V-A-2

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers
Along the Yellowstone River, Southeastern Montana

After: Torrey and Swenson, 1951

(data in parts per million unless otherwise noted)

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as $CaCO_3$	F	B
Alluvium and Terrace	*	560	26	0.06	33	17	153	440	102	8	2.2	152	0.4	0.17
	*	1560	22	0.16	16	7.4	548	780	414	96	64	70	1.0	0.77
	*	934	29	6	98	55	152	576	302	13	1.7	470	0.4	0.22
	AVE	1018	26	2	49	26	284	599	273	39	23	231	2.6	0.4
Fort Union Formation	*	656	35	0.6	74	31	119	568	99	13	1.1	312	0.4	0.08
	*	3710	15	0.2	233	255	582	646	2220	63	22	1630	0.9	0.46
	*	4900	28	0.2	305	470	561	376	3140	94	115	2690	0.9	0.57
	*	7520	9.8	0.2	214	272	1813	625	4860	26	2.1	1650	0.6	1.3
	AVE	4196	22	0.3	206	257	769	554	2580	49	6.7	1570	0.7	0.6
Hell Creek and Fort Union Formation Undifferentiated	MAX	1760	15	1.5	6	2.0	737	1950	54	53	2.5	19	6	0.96
	AVE	966	13	0.2	4.3	0.4	394	898	14.7	34	1.2	12	2.3	0.6
	MIN	772	11	0.02	2	0.0	310	642	2.4	22	0	5	1.4	0.0

* Individual Analysis

After: Torrey, Alfred E. and Frank A. Swenson, 1951, "Ground-Water Resources of the Lower Yellowstone River Valley Between Miles City and Glendive, Montana", with a section on the "Chemical Quality of the Water" by Herbert A. Swenson, U.S. Geological Survey Circular 93.

TABLE V-A-3

Results of Chemical Analyses of Ground Water Collected From Principal Shallow Aquifers in Southeastern Montana

(data in parts per million unless otherwise noted)

After: Perry, 1935

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Alluvium	MAX	10260	30	0.2	343	317	2369	1057	5531	492	-	2157	-	-
	AVE	2697	24	0.2	121	94	603	614	1286	105	-	686	-	-
	MIN	661	15	T	19	19	58	376	183	2	-	163	-	-
Fort Union Formation	MAX	3041	35	8	317	201	901	2175	1640	70	-	1616	-	-
	AVE	1596	12.8	3.6	59	53	448	926	499	30	-	365	-	-
	MIN	447	0.8	0	1	2.9	77	171	2.8	4	-	23	-	-
Fox Hills Formation (sandstone)	*	1243	23	17	9	1.5	448	716	285	9	-	28	-	-
Judith River Formation	*	4542	14	15	322	192	814	673	2658	17	-	1592	-	-

After: Perry, Eugene S., 1935, "Geology and Ground-Water Resources of Southeastern Montana", Montana School of Mines, Montana Bureau of Mines and Geology Memoir No. 14.

* Individual Analysis

TABLE V-A-4

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers in The Northern Powder River Valley of Montana

(data in parts per million unless otherwise noted)

After: Taylor, 1968

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Terrace (alluvial) Deposits	*	934	-	6.0	98	55	152	576	302	13	1.7	470	0.4	-
	*	1710	-	-	89	103	336	578	825	41	11	646	0.8	-
	AVE	1322	-	6.0	94	79	244	577	564	27	6	558	0.6	-
Fort Union Formation	*	754	-	25.4	92	127	210	918	413	8	9.3**	754	0.5	-
Upper Hill Creek Formation	MAX	1290	-	17.4	88	31	408	965	485	40	3.2	347	5.5	
	AVE	887	-	2.1	10	4	353	772	108	19	0.5	41	3.1	
	MIN	762	-	0.0	0	0	305	613	16	11	0.0	0	1.1	
Fox Hills Sandstone and Basal Hell Creek Formation	MAX	1170	-	2.1	9	3	442	810	356	43		33	2.5	
	AVE	796	-	0.2	2	0.2	326	628	108	23	0.0	6.3	1.5	
	MIN	674	-	0.0	0	0	275	506	15	9		0	0.6	

* Individual Analysis

** Probably contaminated by nearby barnyard

After: Taylor, O. James, 1968, "Ground Water Resources of the Northern Powder River Valley, Southeastern Montana", Montana Bureau of Mines and Geology. Bulletin 66.

TABLE V-A-5

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers in Rosebud County, Montana

After: Renick, 1929

(data in parts per million unless otherwise noted)

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Alluvium	MAX	10260	39	8	452	317	2369	1247	3628	492	343	2157	-	-
	AVE	2230	25	1.7	115	81	508	558	1112	38	21	606	-	-
	MIN	555	15	T	2.7	2.1	40	122	87	2	T	21	-	-
Fort Union Formation	MAX	3736	31	19	336	215	571	1427	2440	88	6	1722	-	-
	AVE	1251	19	1.9	62	52	302	618	458	21	2.1	368	-	-
	MIN	294	9.6	0.1	4	1.2	16	173	2.6	2	0.0	15	-	-
Judith River Formation	MAX	4542	16	15	322	281	1220	878	2658	28	20	1650	-	-
	AVE	1881	13	2.6	122	76	374	416	1015	16	6.9	615	-	-
	MIN	328	6.4	0.2	27	7	14	154	88	3	T	96	-	-

After: Renick, B. Coleman, 1929, "Geology and Ground-Water Resources of Central and Southern Rosebud County, Montana", "With Chemical Analyses of the Waters" by H. B. Riffenburg, U.S. Geological Survey Water-Supply Paper 600.

TABLE V-A-6

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers in The Little Bighorn Valley

(data in parts per million unless otherwise noted)

After: Moulder et al, 1960

Aquifer Sampled	TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Alluvium, Terrace Deposits, etc.	1420	23	-	95	98	235	465	730	6.5	0.3	639	0.4	0.62
	1290	20	-	83	47	284	485	608	6.5	0.5	401	0.3	0.28
	999	20	-	91	78	131	441	445	3.0	3.7	547	0.5	0.25
(Each line represents one well)	844 c	13	-	89	52	125	387	365	6.0	2.0	436	0.3	0.31
	641 c	15	0.08	108	38	66	452	178	6.5	5.5	426	0.2	0.18
	782 c	17	-	87	57	101	449	288	4.5	6.0	452	0.3	0.26
	555 c	16	0.65	124	41	19	507	100	3.0	0.2	479	0.1	0.06
	606 c	12	-	129	41	37	543	106	3.0	11	490	0.2	0.16
	1070	11	-	129	74	113	456	485	6.5	0.1	626	0.3	0.40
	530	11	3.5	101	34	36	370	154	2.0	1.3	390	0.1	0.16
	555	16	1.1	82	40	49	349	162	3.5	3.8	367	0.2	0.11
	1020	16	3.9	148	46	133	496	420	7.5	0.1	557	0.2	0.10
	2880	19	3.4	174	92	607	550	1600	45	0.2	814	0.5	1.3
	492	22	1.7	76	31	45	283	173	3.5	0.6	319	0.1	0.07
	4630	22	5.5	189	208	880	626	2600	72	0.3	1330	0.6	2.0
	1530	19	-	82	58	361	600	695	12	0.0	442	0.5	0.48
	3920	25	-	166	132	852	542	2330	18	1.0	958	0.6	0.23
	3040	23	2.0	223	155	442	479	1730	17	1.9	1190	0.5	0.53
	1180	25	0.84	86	76	193	443	570	4	0.1	525	0.3	0.40
	1650	19	-	163	84	250	500	830	15	0.3	750	0.5	0.44
	1840	18	-	113	79	382	538	960	13	1.1	606	0.4	0.71
	7720	14	2.3	430	382	1259	596	4630	148	0.0	2650	0.7	1.4
	648 c	24	1.6	60	66	70	432	207	3	2.1	420	0.5	0.25
	400	15	3.1	58	28	36	218	135	2	0.3	260	0.3	0.20
	600	10	-	68	39	70	244	269	3	1.2	330	0.3	0.22
	2330	22	-	207	155	237	429	1240	17	0.9	2330	0.4	0.47

c = calculated

TABLE V-A-6 (cont'd)

Aquifer Sampled	TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Alluvium, Terrace Deposits, etc.	2380	28	0.24	251	152	209	393	1300	17	0.8	1250	0.5	0.89
	563	20	-	63	52	56	362	189	3	0.6	371	0.4	0.30
	524	18	0.74	55	37	67	263	209	5.5	1.0	291	0.5	0.37
	649	16	0.97	95	42	64	344	245	9.5	0.7	408	0.2	0.17
AVE	1576	18	1	127	83	370	441	798	15.5	1.5	701	.3	.44
Parkman Sandstone	1000	10	0.04	3.5	0.1	349	419	408	4.5	2.0	9	0.2	0.38
	1160	8.8	0.04	5.5	0.1	407	455	480	13	1.8	14	0.8	0.54
	1180	10	0.17	3.0	0.1	413	413	520	8	2.5	8	0.3	0.24
	1830	9.9	0.64	6.5	1.5	625	450	935	29	3.3	22	0.3	0.42
AVE	1292	9.9	0.22	4.6	0.4	448	434	580	14	2.4	13	0.4	0.39

V-B North Dakota

In the area of western North Dakota, the shallowest aquifers are comprised of glacial deposits, valley alluvium, and terrace fill. The latter are extensive along the Missouri, Little Missouri, Heart, Knife, and Cannonball Rivers. The major shallow bedrock aquifer in western North Dakota is the Fort Union Formation of Cenozoic age. Substantive Mesozoic aquifers include the Fox Hills Sandstone and the Dakota Sandstone. Deeper strata than the Dakota have not generally been tested for water quality in North Dakota.

Simpson and Riffenburg[1] list limited water quality data for these aquifers as shown in Table V-B-1.

Additional data derived from a test drilling conducted in the vicinity of Beulah, Mercer County, North Dakota are presented in Table V-B-2. Water from these wells ranged from sodium-bicarbonate to sodium-fulfate to calcium-bicarbonate. Iron concentrations were moderate to high. The Fort Union Formation sample was also characterized by sodium-bicarbonate waters which were much softer than the waters of the alluvial formations.

Table V-B-3 presents additional data for the Fort Union and Fox Hills aquifers in North Dakota.

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[1] Simpson, Howard E. and Harry B. Riffenburg, 1959, "Geology and Ground Water Resources of North Dakota", U.S. Geological Survey Water Supply Paper 598.

TABLE V-B-1

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers in North Dakota

(data in parts per million unless otherwise noted)

After: Simpson and Riffenburg, 1929

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Fort Union Formation	MAX	4386	36	3.0	186	78	1499	2152	2185	1135	181	690	-	-
	AVE	1281	19	0.65	4.0	20	417	851	256	81	7.4	171	-	-
	MIN	274	8.6	T	37	1	8	303	3	1	T	14	-	-
Fox Hills Sandstone	MAX	2441	46	0.80	197	65	951	1174	848	824	24	749		
	AVE	1439	28	0.36	67	28	422	853	329	114	4.9	280		
	MIN	592	13	T	7.4	23	55	500	5.9	4	T	28		
Dakota Sandstone	MAX	4799	33	9.9	204	70	1710	1025	1989	1832	15	772		
	AVE	3017	19	1.9	53	18	991	473	981	670	2.9	206		
	MIN	1056	7.6	T	5.6	24	320	171	64	70	T	22		

TABLE V-B-2

Results of Chemical Analyses of Ground Water Collected From Principal Shallow Aquifers Near Beulah, North Dakota

After: Bradley and Jensen, 1962

(data in parts per million unless otherwise noted)

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as $Ca\ CO_3$	F	B
Alluvium	*	540	-	5.6	61	37	85	348	152	0.0	0.0	308	0.1	0.25
	*	576	-	0.25	53	24	65	371	55	8	-	232	0.15	-
	*	500	-	1.3	58	22	41	325	45	8	-	236	0.1	-
	*	1790	-	17	193	75	284	616	761	11	0.0	791	0.1	0.2
	AVE	852	-	6	91	40	119	415	253	7	0.0	392	0.1	0.2
Tongue River Member of Fort Union Formation	*	1330	11	0.2	12	5.9	511	1020	190	0.0	1.8	54	1.1	2.3

After: Bradley, Edward and H. M. Jensen, 1962, "Test Drilling Near Beulah, N. D.", N. D. State Water Conservation Commission, Bismarck, N. D. Ground Water Studies #40.

* Individual Analysis

TABLE V-D-3

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers Near Hettinger (Adam County), North Dakota

After: Robinove, 1956

(data in parts per million unless otherwise noted)

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as $CaCO_3$	F	B
Fort Union Formation	MAX	3290	-	2.6	161	373	423	956	1360	156	17	1940	5	-
	AVE	1295	-	1.2	82	92	204	586	345	80	6.1	539	2.8	-
	MIN	274	-	0.19	12	2.4	7.7	215	12	T	T	10	0.1	-
Fox Hills Sandstone	*	1000	-	0.7	-	2.2	420	604	45	130	6	9	3.5	-
	*	1070	-	T	2.4	4.5	423	894	24	128	0.3	28	3.2	-
	AVE	1035	-	0.7	2.4	3.4	422	749	34	129	3.2	18	3.4	-

* Individual Analysis

After: Robinove, C. J., 1956, "Geology and Ground-Water Resources of the Hettinger Area, Adams County, North Dakota", North Dakota Ground-Water Studies No. 24.

V-C

South Dakota

Ground water in northwestern South Dakota is generally found in the Fort Union Formation of Cenozoic age, and the Minnelusa Formation, the Madison Group (Madison and Pahasapa Limestones) of Paleozoic age. Other formations may produce small quantities of water and the water is generally strongly mineralized. Table V-C-1 summarizes data on the chemical character of selected ground waters in South Dakota as presented by the U.S. Geological Survey and others[1]. Because of the limited data, averages have not been calculated. The data suggest water of better quality, in terms of total dissolved solids, in the Hell Creek, Fox Hills, and Pahasapa aquifers compared to the Fort Union and Dakota aquifers.

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[1] U.S. Geological Survey, et al, 1964, "Mineral and Water Resources of South Dakota", U.S. Geological Survey report to Committee on Interior and Insular Affairs, U.S. Senate.

TABLE V-C-1

Results of Chemical Analyses of Ground Water Collected From Principal Aquifers in South Dakota

After: U. S. Geological Survey et al, 1964

(data in parts per million unless otherwise noted)

Aquifer Sampled		TDS	SiO_2	Fe	Ca	Mg	Na and K	HCO_3	SO_4	Cl	NO_3	Hardness as Ca CO_3	F	B
Fort Union Formation	*	1670	17	0.69	9.6	3.3	570	645	729	11	3	38	-	-
	*	3200	-	0.30	82	49	949	875	1660	9.6	-	406	-	-
Hell Creek Formation	*	758	15	0.07	2.4	0	293	540	165	10	1.1	6	0.6	-
	*	1270	8.8	0.22	5.1	1.6	467	720	402	9.6	1.4	19	1.4	1.2
Fox Hills Sandstone	*	784	12	0.09	33	6.0	237	400	284	1.1	2.5	107	0.4	0.25
	*	1070	10	0	4.1	0.2	424	652	19	268	0.1	11	1.9	1.6
Dakota Sandstone	*	2270	13	10	416	93	98	168	1270	105	0	1420	2.9	0.22
	*	1990	9	0.37	55	13	558	118	1190	67	0.1	190	1.2	1.5
Pahasapa Limestone	*	198	21	0.03	40	13	12	193	12	2	1	153	0.3	-
	*	2210	29	2.9	383	106	103	171	1280	70	0	1390	4.2	0.33
	*	1210	38	0.97	232	58	28	158	650	22	0.2	819	2.2	0.10

* Individual Analysis

V-D Wyoming

The general geology of eastern Wyoming is also indicated by the stratigraphic correlation charge for Montana reproduced as Figure V-D-1. Ground water is found at varying depths throughout the geologic section. Throughout Wyoming, the shallow alluvial aquifers and terrace deposits have received the most attention due to the ease of drilling and the fact that water quality was usually acceptable. Such aquifers exist along the North Platte River, the Powder River, the Tongue River, Bighorn River and Belle Fourche River of Wyoming. In select areas such as the Bighorn River water shed and near the Black Hills of South Dakota, structural discontinuities cause older and normally deeper formations to outcrop and limited drilling has shown that appreciable water supplies exist. In particular, the Mesozoic Lakota and Fall River Formations and the Pahasapa, Limestone and Minnelusa Sandstone of the Paleozoic Era are aquifers in the Black Hills (western) area. In the Bighorn River basin, the Tensleep and Madison Formations contain potential ground water supplies as do these same formations in the Yellowstone River basin of Montana.

Water quality is expected to be similar to that of the same aquifers in Montana.

V-E Potential Impacts on Ground Water Quality

One may reasonably speculate on the potential degradation of water quality caused by mining coal, discharging water-borne ash and boiler scale to surface reservoirs, and domestic activities that will increase as a result of growth in population. Examples of specific cases of ground water pollution or contamination caused by these activities are available. However, there are also cases of less obvious or less expected contamination of ground water supplies that may occur with coal development in the Northern Great Plains. These involve the saline and sodium-rich soils that occur in parts of the area. Construction activities, mining, storage of makeup water, and agricultural activities may sufficiently disturb the soils so as to enhance leaching of salts and to enhance precipitation of the salts on the ground surface. In many locales, the adverse impact on land quality by evaporation of salts on the surface may be viewed today. Road construction in the Northern Great Plains, especially in eastern Montana and eastern Wyoming, has caused additional salinity problems in the more sensitive soils.

More recent measurements in the vicinity of Colstrip, Montana show the deleterious effect of mining of the Rosebud coal seam of the Fort Union Formation on both ground water and surface water quality (Table V-E-1).

Tables 2.2-31 and 2.2-32 of the Westinghouse Environmental Analysis are reproduced as Table V-E-1 here. Increases in total dissolved solids in the surface waters are shown from samples 24L to 25L. Somewhat higher lead, nickel, and zinc concentrations in water samples from spoils are noteworthy.

The Northern Great Plains Resources Program has initiated a larger effort, through the U.S. Geological Survey and the Montana Bureau of Mines and Geology, to further evaluate the impact of mining on ground water quality in the Northern Great Plains. Preliminary information on the quality of ground water near Gascoyne, North Dakota is provided in Table V-E-2. The sample collections and chemical assays were performed by the District Office of the U.S. Geological Survey, Bismarck, North Dakota in cooperation with the State of North Dakota.

TABLE V-E-1

Chemical Analyses Results of Water Near Colstrip, Montana*
(Data are in milligrams per liter (ppm) except as indicated)

Field Chemical Analyses

Sample Number (F - field analysis)	Land surface Altitude feet	Water Temperature °C	Calcium (Ca)	Magnesium (Mg)	Bicarbonate (HCO$_3$)	Carbonate	Sulfate (SO$_4$)	Chloride (Cl)	Fluoride (F)	Nitrate (NO$_3$)	Iron (Fe)	Manganese (Mn)	Specific conductance (micromhos/cm at 25°C)	pH	Date Sampled	Sample Type	Remarks, water source
1F	3430	5	120	73	465	0	312	2	0.4	5.2	0	0.1	1040	7.10	3-16-73	Spring	Clair Streeter owner, sandstone aquifer 100 ft above Rosebud coal
2F	3165	12	50	52	378	0	131	7.0	0.3	46	0	0	600	7.80	3-24-73	Mine pit	Pit 6, seepage from Rosebud coal bed
3F	3257	9	98	62	468	0	212	7.5	0.3	0.9	0.1	—	875	7.42	3-18-73	Well	Leo Farley owner, Rosebud coal aquifer
4F	3294	—	120	153	526	0	788	10	0.4	0	—	0.2	1380	7.23	3-15-73	Well	Jim Snider owner, Rosebud coal aquifer
5F		—	140	158	366	0	887	13	0.5	6.0	1.0	—	1680	7.60	3-18-73	Well	Leo Farley owner, McKay coal aquifer
6F	3238	8	204	216	294	0	1625	13	0.7	0.3	0.2	0	2400	6.85	3-16-73	Pit	Bulldozer pit in McKay coal
7F	—	—	138	317	585	0	1625	14	0.6	0.5	1.8	—	2500	7.65	3-16-73	Well	Duke McRae owner, McKay coal aquifer
8F	—	10	162	154	564	0	1875	16	1.6	0	1.5	0.2	3400	7.35	3-20-73	Well	B and R Food Town, sandstone aquifer 200 ft below Rosebud coal
9F	3330	13	20	0	431	0	1440	12	0.8	0.3	1.0	—	2300	7.80	3-19-73	Well	Leo Farley owner, sandstone aquifer 350 ft below Rosebud coal
10F	3248	—	126	131	262	0	775	15	0.5	0.3	0.4	—	1500	7.42	3-23-73	Well	Jim Snider owner, alluvial aquifer along E. Fork Armells Creek
11F	3222	9	148	129	366	0	975	13	0.6	0.2	0.1	—	1630	7.80	3-19-73	Ditch	Ditch east of Armells Creek, collects seepage from water table
12F	3235	5	100	394	242	0	2062	20	0.8	0	0.1	0.2	2950	7.85	3-15-73	Pit 1 pond	Swimming hole, in Pit 1 spoils, partial ice cover
13F	3235	8	110	498	292	0	2250	27	1.0	0.2	0.1	—	3750	7.75	3-20-73	Pit 1 pond	Swimming hole, in Pit 1 spoils, slight ice cover
14F	3237	—	234	222	372	0	1510	12	0.9	0.4	0	—	2200	7.37	3-15-73	Spring	Spring supplying "swimming hole" at southwest end, sandstone aquifer
15F	3229	—	200	277	373	0	2000	18	0.9	0.1	0	—	3300	7.22	3-15-73	Ditch	Ditch draining Pit 1 spoils, ponded, no flow
16F	3236	—	150	310	220	0	1740	13	0.6	0	0.5	0.2	2200	7.50	3-15-73	Pit 2 pond	Shallow pond in Pit 2 spoils
17F	3258	—	490	745	670	0	4000	7.5	1.4	0.1	0	—	5000	7.20	3-23-73	Pit 1 spoils	Spoils water from test-hole number 2
18F	3257	—	398	264	500	0	2080	13	0.9	0.1	0	—	2800	7.10	3-23-73	Pit 1 spoils	Spoils water from test-hole number 3
19F	3252	—	405	480	975	0	2620	15	1.0	0	0	—	3800	6.85	3-23-73	Pit 1 spoils	Spoils water from test-hole number 4
20F	3264	—	348	335	622	0	2100	13	0.9	0.7	0	—	2900	6.76	3-23-73	Pit 1 spoils	Spoils water from test-hole number 5
21F	3244	7	180	226	648	0	1312	15	0.6	0	0.6	1.7	2000	7.45	3-15-73	Armells Creek	Upstream from Colstrip at highway bridge, est. 0.2 cfs
22F	3244	9	206	208	634	0	1250	12	0.7	1.5	0.2	0.7	2200	7.41	3-20-73	Armells Creek	Upstream from Colstrip at highway bridge, est. 0.2 cfs
23F	3222	7	210	224	570	0	1125	16	0.5	0	0.6	—	2100	7.62	3-15-73	Armells Creek	Downstream from Colstrip at county road bridge, est 0.2 cfs

* After: "Colstrip Generation and Transmission Project, Applicant's Environmental Analysis", November, 1973 - Westinghouse Environmental Systems

TABLE V-E-1 (cont'd)

Laboratory Chemical Analyses

Sample Number (L = laboratory analysis)	Nickel (Ni)	Selenium (Se)	Beryllium (Be)	Date Sampled	Type of Sample	Remarks, Credits, Water Source
2L	<0.04	<0.005	<0.02	3-24-73	mine pit	Pit number 6, drainage from Rosebud coal bed
3L	<0.04	<0.005	<0.02	3-18-73	well	Leo Farley owner, Rosebud coal aquifer
9L	<0.04	<0.005	<0.02	3-19-73	well	Leo Farley owner, sandstone aquifer 350 feet below Rosebud coal
8L	0.04	<0.005	<0.02	3-20-73	well	B & R Food Town (store, bar, gas station, restaurant), sandstone aquifer 200 feet below Rosebud coal
13L	0.06	<0.005	<0.02	3-20-73	Pit 1 pond	"Swimming hole" in Pit 1 spoils, slight ice cover
17L	0.14	<0.005	<0.02	3-23-73	Pit 1 spoils	Spoils water from spoils test-hole number 2
18L	0.06	<0.005	<0.02	3-23-73	Pit 1 spoils	Spoils water from spoils test-hole number 3
19L	0.10	<0.005	<0.02	3-23-73	Pit 1 spoils	Spoils water from spoils test-hole number 4
20L	0.08	<0.005	<0.02	3-23-73	Pit 1 spoils	Spoils water from spoils test-hole number 5
11L	<0.04	<0.005	<0.02	3-20-73	ditch	Ditch providing local drainage to E. Fork Armells Creek
22L	<0.04	<0.005	<0.002	3-20-73	stream	E. Fork Armells Creek upstream from Colstrip, estimated discharge 0.2 cfs
24L	—	—	—	8-12-72	stream	E. Fork Armells Creek upstream from Colstrip, stream ponded, no flow, MBMG analysis
25L	—	—	—	8-12-72	stream	E. Fork Armells Creek downstream from Colstrip, stream ponded, no flow, MBMG analysis
26L	—	—	—	8-26-71	stream	E. Fork Armells Creek 1500 yds. downstream from Colstrip, Yapuncich, Sanderson & Brown, analyses, Billings
27L	—	—	—	7-31-23	well	Water from Rosebud coal, USGS analysis
28L	—	—	—	7-22-23	well	Water from Rosebud coal, USGS analysis
29L	—	—	—	7-15-23	well	Aquifer probably sandstone 250 ft below Rosebud coal, USGS analysis
30L	—	—	—	7-15-23	well	Aquifer probably sandstone 300 ft below Rosebud coal, USGS analysis
31L	—	—	—	7-15-23	well	Alluvium aquifer along Rosebud Creek, USGS analysis
32L	—	—	—	7-20-23	well	Alluvium aquifer, USGS analysis
33L	—	—	—	9-14-23	well	Water from sandstone in lower Tongue River member, USGS analysis
34L	—	—	—	7-30-23	well	Water from Tullock member, USGS analysis
35L	—	—	—	7-30-23	well	Water from Rosebud coal bed, USGS analysis
36L	—	—	—	1923	well	Sandstone aquifer about 250 feet below Rosebud coal, Northern Pacific Railway analysis
37L	—	—	—	1923	spring	Water from Rosebud coal, Northern Pacific Railway analysis
38L	—	—	—	1923	test boring	Aquifer unknown, Northern Pacific Railway analysis
39L	—	—	—	1923	test boring	Aquifer unknown, Northern Pacific Railway analysis
40L	—	—	—	1923	coal shaft	Water from Rosebud coal, Northern Pacific Railway analysis
41L	—	—	—	1923	stream	Water hole 6 ft deep in E. Fork Armells Creek, Northern Pacific Railway analysis

TABLE V-E-1 (cont'd)

Laboratory Chemical Analyses

Sample Number (L = laboratory analysis)	Land Surface Altitude ft	Water Temperature °C	Laboratory specific conductance - micromhos per centimeter at 25°C	Laboratory pH	Dissolved Solids (calculated Nos 1-14 and 21-26 evap at 180°C Nos 15-20)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO₃)	Carbonate (CO₃)	Sulfate (SO₄)	Chloride (Cl)	Nitrate (NO₃)	Iron (Fe)	Silica (SiO₂)	Total Phosphate (PO₄)	Fluoride (F)	Manganese (Mn)	Boron (B)	Copper (Cu)	Chromium (Cr)	Lead (Pb)	Arsenic (As)	Mercury (Hg)	Cadmium (Cd)	Zinc (Zn)
2L	3165	12	624	8.19	535	45	47	20	2.8	244	0	104	3.3	47.4	0.1	21	0.13	0.2	0.05	0.21	<0.02	<0.02	<0.05	<0.002	<0.0002	<0.01	<0.01
3L	3357	9	869	7.51	802	72	74	26	3.0	451	0	147	5.9	4.1	0.1	19	0.08	0.2	0.02	<0.1	<0.02	<0.02	<0.05	<0.002	<0.0002	<0.01	0.10
8L	3330	13	2610	8.04	2032	14	3.4	603	3.6	413	0	978	7.9	0.1	0.6	7.1	0.09	0.4	0.02	<0.1	<0.02	<0.02	<0.05	<0.002	0.0003	<0.01	0.06
9L	—	10	3460	7.43	3155	163	153	550	10	547	0	1704	13	0.2	1.3	13	<0.05	0.5	0.09	0.45	<0.02	<0.02	0.10	<0.002	<0.0002	<0.01	0.02
13L	3235	6	3880	7.97	3832	105	541	225	19	285	0	2630	23	0.4	0.1	2.8	0.07	0.1	0.22	0.26	<0.02	<0.02	0.16	<0.002	<0.0002	<0.01	0.01
17L	3258	—	4860	7.32	5626	481	748	23	11	697	0	3640	3.2	0.3	0.3	17	0.13	0.2	4.7	0.17	0.02	0.02	0.19	<0.002	<0.0002	<0.01	0.19
18L	3257	—	2848	7.19	2881	347	280	52	15	500	0	1650	11	0.5	0.4	24	0.10	0.1	0.32	0.86	0.03	<0.02	0.13	<0.002	<0.0002	<0.01	0.84
19L	3252	—	3860	7.04	4174	380	477	81	13	973	0	2212	12	1.1	1.1	19	0.09	0.1	5.0	0.46	0.03	0.02	0.19	<0.002	<0.0002	<0.01	0.45
20L	3264	—	2994	6.94	3058	333	317	58	12	629	0	1668	14	4.4	0.1	21	0.15	0.1	2.2	1.2	<0.02	<0.02	0.16	<0.002	<0.0002	<0.01	0.27
21L	3222	8	1725	7.81	1549	138	132	108	9.3	348	0	785	10	0.5	0.1	7	0.12	0.2	0.29	0.29	<0.02	<0.02	<0.05	<0.002	<0.0002	<0.01	0.01
22L	3248	9	2370	7.52	2316	195	219	127	12	598	0	1131	12	0.2	0.5	20	0.08	0.2	1.8	0.45	<0.02	<0.02	<0.05	<0.002	<0.0002	<0.01	0.01
24L	3248	20	2220	8.09	2011	110	218	145	13	342	0	1150	12	1.2	<0.1	20	—	0.2	0.01	—	—	—	—	—	—	—	—
25L	3222	18	3560	7.88	3726	335	319	288	5.6	489	0	2208	29	19	<0.1	25	—	0.2	0.01	—	—	—	—	—	—	—	—
26L	—	—	3636	8.2	3389	216	423	255	—	770	0	2102	13	0	0.1	—	—	—	0	—	—	—	—	—	—	—	—
27L	—	—	—	—	334	13	17	20	—	63	0	56	6	24	6.9	38	—	—	—	—	—	—	—	—	—	—	—
28L	—	—	—	—	366	54	45	16	—	320	19	49	3	Tr	Tr	14	—	—	—	—	—	—	—	—	—	—	—
29L	—	—	—	—	1884	104	92	346	—	390	0	1008	9	2.2	1.2	13	—	—	—	—	—	—	—	—	—	—	—
30L	—	—	—	—	1160	14	9.1	380	—	371	0	531	8	1.9	Tr	10	—	—	—	—	—	—	—	—	—	—	—
31L	—	—	—	—	2488	194	172	296	—	547	0	1300	20	1	8	18	—	—	—	—	—	—	—	—	—	—	—
32L	—	—	—	—	1304	90	122	148	—	593	0	537	6	2	0.8	18	—	—	—	—	—	—	—	—	—	—	—
33L	—	—	—	—	1454	148	160	63	—	464	0	716	8	5	2.5	23	—	—	—	—	—	—	—	—	—	—	—
34L	—	—	—	—	732	4.4	2.4	305	—	732	36	2.8	18	Tr	0.40	9.2	—	—	—	—	—	—	—	—	—	—	—
35L	—	—	—	—	1351	144	135	92	—	517	0	634	11	1.5	5.3	28	—	—	—	—	—	—	—	—	—	—	—
36L	—	—	—	—	2029	67	12	233	—	1210	—	1045	20	10	—	—	—	—	—	—	—	—	—	—	—	—	—
37L	—	—	—	—	718	114	51	38	—	357	—	268	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
38L	—	—	—	—	2446	114	236	258	—	426	—	1343	35	36	—	—	—	—	—	—	—	—	—	—	—	—	—
39L	—	—	—	—	1558	136	103	244	—	337	—	684	—	24	—	—	—	—	—	—	—	—	—	—	—	—	—
40L	—	—	—	—	1102	98	87	153	—	794	—	259	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—
41L	—	—	—	—	962	128	106	146	—	497	—	295	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE V-E-2

Results of Water Quality Analyses of
Collected in Vicinity of Gascoyne Mine
1974

("Peerless Mine")

				mg/l										
Locations	1974 Date	Specific Conductance µmhos	pH	CO_2	Alkalinity $CaCO_3$	HCO_3	CO_3	NO_3 (N)	NO_3 + NO_2 (N)	P	TOC	Ca	Mg	Na
1. 0.2 mi SW of Gascoyne Mine	10/23	3110	8.5	3.4	557	630	24	0.23	--	--	--	28	12	670
	11/26	3100	8.6	2.8	562	645	20	--	--	--	17.6	24	7	680
2. 0.3 mi SW of Gascoyne Mine	10/22	6790	8.2	5.6	451	550	0	0.23	--	--	--	85	65	1500
	11/26	8100	8.4	3.6	468	570	0	--	--	--	25.4	25	41	1800
3. 1.3 mi ESE of Gascoyne Mine	5/25	2470	8.3	5.6	577	689	7	--	--	--	--	13	6.4	580
	6/5	2230	8.0	11.0	565	689	0	--	0.02	0.06	--	13	7.2	530
	11/20	2200	8.3	5.5	568	692	--	--	--	--	30.7	16	11	470
	11/21	4450	8.4	4.0	510	608	7	--	--	--	17.1	88	55	820
4. 0.9 mi S of Gascoyne Mine	5/22	6390	9.7	0.1	126	40	56	--	0.06	0.23	--	170	1.6	1400
	8/20	5240	10.0	0.0	171	6	100	0.23	--	--	--	100	2.4	1200
5. 1.5 mi WSW of Gascoyne Mine	4/30	3730	7.4	36	516	629	--	--	0.17	0.34	--	130	100	630
	11/20	3800	7.8	17	537	655	--	--	--	--	20.5	130	100	670
6. 0.8 mi E of Gascoyne Mine	4/23	1290	8.5	3.6	584	679	16	--	0.05	0.90	--	7.4	1.7	320
	11/27	1580	8.9	1.5	611	696	24	--	--	--	55.4	5.8	1.1	370
7. 2.0 mi WNW of Gascoyne Mine	5/1	1620	8.5	3.7	599	665	32	--	0.09	1.9	--	9.2	2.8	380
	11/22	1800	8.8	1.9	602	689	22	--	--	--	19	5.5	2.8	400
8. 0.7 mi NNW of Gascoyne Mine	5/17	--	--	--	--	--	--	--	--	--	--	--	--	--
	8/28	--	--	--	550	670	0	--	--	--	--	4.4	13	510
	11/21	2350	8.4	4.3	557	671	4	--	--	--	>21	6.9	4.3	500
	11/21	2350	8.5	3.4	550	671	0	--	--	--	11.4	6.2	4.2	500
9. 2.0 mi WNW of Gascoyne Mine	5/24	1860	8.6	3.0	603	695	20	0.23	--	--	--	9.3	3.6	450
	6/2	1880	8.5	3.2	514	613	7	--	0.09	--	--	7.0	3.0	420
	6/5	--	--	--	503	613	--	--	--	--	--	--	--	--
10. 1.0 mi N of Gascoyne Mine	4/25	1860	8.7	3.0	809	788	98	--	--	1.6	--	24	7.8	430
	11/25	2340	9.0	1.7	870	914	72	--	--	--	44	24	18	500

nd Water
coyne, N.D.

CONCENTRATIONS (dissolved unless noted)

					ug/1													
K	Cl	SO4	F	SiO2	As D/S*	Be	B	Cd D/S*	Cr	Cu D/S	Fe D/S	Pb	Mn D/S	Mo D/S	Ni	V	Zn D/S	Al D/S
.0 .9	7.2 11	1000 910	2.5 2.0	7.3 13	-- 10/5	-- <10	1100 1000	-- 1/<9	-- <10	-- 7/<3	100/-- 20/540	-- 7	40/-- 90/20	-- 19/5	-- 2	-- 5.2	-- 620/680	-- 10/4
2 4	6.8 9.1	3100 3500	1.0 0.7	12 8.7	-- 4/1	-- <10	1900 1600	-- 1/9	-- <10	-- 2/8	130/-- 30/370	-- 1	160/-- 380/10	-- 1/2	-- 2	-- 1.5	-- 1400/300	- 10/
4.4 5.1 5.9 1	110 81 40 45	570 530 470 1600	1.1 1.4 1.3 0.8	9.1 9.4 8.0 10	-- -- 1/3 1/2	-- 0 <10 <10	780 980 -- --	-- 2/-- 1/9 1/9	-- 0 <10 <10	-- 12/-- 150/60 10/0	100/-- 160/-- 370/1330 30/1170	-- 1200 70 5	60/-- 30/-- 70/0 250/40	-- 26/-- 18/4 17/2	-- 12 3 5	-- 0.7 6.4 4.0	-- 1300/-- 1400/600 500/280	- - 40/ 30/
7 7.5	17 15	3200 2500	0.8 1.7	28 29	-- --	-- --	-- 1400	-- --	-- --	-- --	960/-- 920/--	-- --	40/-- 40/--	-- --	-- --	-- --	-- --	
18 15	8.0 6.0	1600 1500	0.4 0.2	13 12	-- 0/c	-- <10	-- --	-- 1/<9	-- <10	-- 2/<8	590/-- 10/4190	-- 1	280/-- 500/20	-- 0/2	-- 3	-- 0	-- 750/550	0
3.0 2.9	33 91	150 130	5.2 6.8	10 8.6	-- 5/11	-- <10	-- --	-- 1/9	-- <10	-- 1/9	530/-- 310/1090	-- 9	70/-- 80/1700	-- 28/22	-- 0	-- --	-- 250/180	230
4.2 3.6	8.6 51	290 260	1.3 0.9	9.7 9.8	-- 3/2	-- <10	-- --	-- 1/<9	-- <10	-- 7/<3	190/-- 60/4840	-- 11	40/-- 60/30	-- 4/3	-- 10	-- --	-- 290/630	7
-- 11 4.3 4.6	-- 8.5 13 58	-- 600 550 560	-- 2.7 1.9 1.9	-- 6.4 7.4 7.5	-- -- 0/1 1/0	0 -- <10 <10	1100 -- -- --	2/-- -- 2/<8 1/<9	0 -- <10 <10	6/-- -- 10/0 10/0	-- -- 90/190 40/290	12 -- 4 8	-- -- 30/0 20/20	0/- -- 0/2 1/1	4 -- 4 9	4 -- -- --	220/-- -- 30/50 40/50	5 5
4.8 3.6 --	4.4 29 --	390 380 --	1.9 1.9 --	5.7 8.8 --	-- -- --	-- 0 --	220 1300 --	-- 1/-- --	-- 0 --	-- 24/-- --	630/-- 100/-- --	-- 45 --	80/-- 80/-- --	-- 2/-- --	-- 14 --	-- 24 --	-- 310/-- --	
4.6 5.5	66 68	98 350	5.2 3.9	-- 13	-- 5/6	-- <10	-- --	-- 2/<8	-- <10	-- 7/3	770/-- 140/410	-- 12	60/-- 110/10	-- 3/4	-- 1	-- --	-- 450/170	

* D/S = Dissolved/Suspended

ug/1												mg/1	
Cr	Cu D/S	Fe D/S	Pb	Mn D/S	Mo D/S	Ni	V	Zn D/S	Al D/S	Li D/S	Se D/S	TDS	Hg D/S
--	--	100/--	--	40/--	--	--	--	--	--	--	--	2150	--
10	7/<3	20/540	7	90/20	19/5	2	5.2	620/680	10/490	30/0	0/0	2040	<0.1/0.1
--	--	130/--	--	160/--	--	--	--	--	--	--	--	5130	--
0	2/8	30/370	1	380/10	1/2	2	1.5	1400/300	10/490	110/0	0/0	6020	0.3/0.0
--	--	100/--	--	60/--	--	--	--	--	--	--	--	1600	--
0	12/--	160/--	1200	30/--	26/--	12	0.7	1300/--	--	50/--	2/--	1620	0.0/--
0	150/60	370/1330	70	70/0	18/4	3	6.4	1400/600	40/260	30/0	0/0	1420	<0.1/0.0
0	10/0	30/1170	5	250/40	17/2	5	4.0	500/280	30/770	70/0	0/1	3100	<0.1/0.0
--	--	960/--	--	40/--	--	--	--	--	--	--	--	5060	--
--	--	920/--	--	40/--	--	--	--	--	--	--	--	4050	--
--	--	590/--	--	280/--	--	--	--	--	--	--	--	2940	--
0	2/<8	10/4190	1	500/20	0/2	3	0	750/550	0/100	230/0	0/0	2980	<0.1/0.0
-	--	530/--	--	70/--	--	--	--	--	--	--	--	1040	--
0	1/9	310/1090	9	80/1700	28/22	0	--	250/180	230/1500	0/<10	0/0	1050	0.1/0.0
--	--	190/--	--	40/--	--	--	--	--	--	--	--	1080	--
0	7/<3	60/4840	11	60/30	4/3	10	--	290/630	70/3200	10/0	0/0	1100	0.1/0.0
0	6/--	--	12	--	0/-	4	4	220/--	--	30/--	1/--	--	0.0/--
--	--	--	--	--	--	--	--	--	--	--	--	1700	--
0	10/0	90/190	4	30/0	0/2	4	--	30/50	50/350	10/10	0/0	1490	<0.1/0.0
0	10/0	40/290	8	20/20	1/1	9	--	40/50	50/350	20/0	0/0	1490	<0.1/0.0
--	--	630/--	--	80/--	--	--	--	--	--	--	--	1380	--
0	24/--	100/--	45	80/--	2/--	14	24	310/--	--	30/--	2/--	1310	0.0/--
--	--	--	--	--	--	--	--	--	--	--	--	--	--
--	--	770/--	--	60/--	--	--	--	--	--	--	--	1440	--
0	7/3	140/410	12	110/10	3/4	1	--	450/170	40/660	30/0	0/0	1520	0.4/0.1

ssolved/Suspended

CHAPTER VI

MITIGATING MEASURES - IMPACT REDUCTION

Introduction

Measures which can be employed to reduce the impact on water quality have been arbitrarily divided into measures for protection of surface water and ground water.

VI-A Preplanning of Mining

One of the most important measures in protecting water resources is preplanning and careful evaluation of the area to be affected. As a minimum the following steps should be included in any preplanning program.

Preplanning

(1) Background data collection

  (a) Coal sulfur analysis and trace element analysis.

  (b) Analysis of overburden strata nutrient and trace nutrients and phytotoxic parameters, particularly sodium and other alkali elements, and leaching studies.

  (c) Identification of affected aquifers and chemical analyses of their waters.

  (d) Analyses of surface water quality prior to disturbances.

  (e) Collection or compilation of climatological data.

  (f) Identification of native vegetation and the environment of each, including water requirements.

  (g) Other special considerations.

(2) Development of Mining Plan

  (a) Definition of limits of economic recovery.

  (b) Choice of mining equipment based on concurrent and selective overburden replacement.

  (c) Definition of areas unsuitable for mining due to inability to reclaim either economically or within a reasonable time frame.

(d) Establishment of desirable locations and sizing of runoff diversions and control structures.

(e) Estimate the quality and quantity of runoff, diverted water and water pumped from the pit to establish the degree or necessity of water treatment.

(f) Estimate consumptive water use requirements for dust suppression, reclamation and other uses.

(g) Establishment of locations for auziliary facilities to minimize surface disturbance.

(3) Development of Reclamation Plan

(a) Coordinate intimately with mining plan to minimize the degree and term of surface disturbance.

(b) Design slopes to facilitate revegetation efforts by machinery and to provide proper drainage or water retention as appropriate.

(c) Consultation with soil scientists and agronomists in determining patterns for selective replacement of spoil, selection of suitable plant species, irrigation and fertilization requirements and practices, and interim surface stabilization.

(d) Determination of the ultimate land use design from alternates and coordination with surroundings and regional plans.

(e) Provision for topsoil replacement as rapidly as possible without stock piling for excessive periods.

(f) Maintenance of reclaimed areas.

(g) Other considerations.

(4) Cessation of Operation Plan

(a) Continued vegetative and surface stabilization maintenance as required.

(b) Disposition of the final pit.

(c) Sealing of any exposed coal surfaces or other undesirable strata.

(d) Removal and disposal of all surface structures that are not a part of the final land use plan.

(e) Others as appropriate.

Runoff Controls

Numerous structural methods can be employed to control runoff, including highwall diversions, grading, gouging, sediment traps, sediment reservoirs, velocity breakers, mulch, and many others.

The design of all runoff control structures should be based upon local meteorological and geological conditions. Design life for major structures may be considered as the expected life of the mining plus the additional time required for stabilization of the disturbed areas following mining. Individual areas need not be disturbed for this entire period since reclamation should be ongoing with mining.

The design return period for structures should give a reasonable probability of functioning, say 90%, within the design period. Minimum design should be for the calculated runoff from a storm of a ten-year return period which would carry a 90% probability of not being exceeded for a one-year design period. Refer to Appendix II for more details.

Certain circumstances of downstream water rights may require that runoff not be totally impounded or significantly reduced in flow. Consequently, sediment retention reservoirs would, as a necessity, be designed with controlled drawdown features.

In areas where stream flow reduction or downstream water rights do not represent problems, total impoundment of runoff should be considered with the collected waters being utilized for irrigation in revegetation areas.

Reclamation Practices

A completely reclaimed and revegetated area can reduce dissolved and suspended solids loss significantly and in some cases may even improve upon pre-mining conditions.

The mining company should always consult specialists in determining appropriate revegetation methods, particularly on details such as species selection and mix, planting methods and schedules, soil preparation, including mulches, fertilization, texturing and maintenance activities. The U.S. Soil Conservation Service should be consulted.

In areas where total annual precipitation is less than 8 to 10 inches, serious study of the ability to revegetate should be undertaken prior to mining.

Water Treatment

Due to the generally low concentrations of dissolved and total metals in mine discharges in the NGPRP, conventional treatment for acid mine drainage waters will not be required. However, where metals do represent a problem, contaminated waters should be segregated from uncontaminated runoff for separate treatment.

The only wastewater treatment generally required will be conventional biological methods for the small sanitary wastewater volumes and removal of suspended solids from runoff and pit dewatering.

Ground Water Protection

Ground waters must be protected from interruption, contamination through leaching and communication with lesser quality aquifers.

A suggested technique for protection from interruption of aquifers involves replacement of overburden based upon its permeability and chemical character such that aquifers are not blocked or degraded by unsuitable material. It may even be advantageous to lay in graded materials such as limestone, clinker, or slow-leaching rock in the same horizon as the aquifer during overburden replacement in a large, regionally-significant mine.

During operation of the active pit, communication from upper aquifers to others lower is unavoidable if the coal is not underlain by an aquiclude. However, selective overburden replacement, for instance laying down impermeable zones between aquifers, might help to minimize inter-aquifer communication under such circumstances.

It should be obvious that the preplanning described earlier is equally important in protecting against adverse ground water disturbances.

Perhaps the ground water problems represent the most severe water quality hazard with respect to the mining operation. Leaching of highly saline or alkaline spoils that are placed near the surface could be significant in the impact upon ground water and ultimately surface water via springs or inflow to surface water during low stream stage.

Protection against such subtle effects can only be accomplished by careful planning in overburden replacement. It is necessary to run leach tests with cores of overburden to assist in selection of spoils to be placed near the surface.

Alternate Mining Techniques

Longwall mining with controlled subsidence is currently being investigated as a potential method to minimize surface disturbance and the resulting water quality impacts. This technique has not been demonstrated in the NGPRP area, however, and is likely not a substitute mining method for the shallow, thick coal seams that prevail.

Irrigation Controls

By far, the majority of the salinity increase in return flows occurs during percolation through the soil profile. Salts are concentrated in this area by evapotranspiration. Water is in intimate contact with the soil constituents as it passes through and can react with these constituents resulting in degradation in the quality of the percolating water. Processes which may contribute to some extent to this degradation are: 1) ion exchange reactions with the soil minerals, 2) precipitation and dissolution reactions in the soil profile, 3) dissolution and leaching of soluble plant nutrients applied as fertilizer, and 4) salt "pickup" resulting from the presence of natural salt deposits in the soil profile.

To achieve a reduction in salt leaching during percolation through the soil, the amount of time the water is in contact with the soil should be reduced. In some cases tile drains will accomplish this by skimming the water off below the root zone. Thus, the irrigation water will not percolate through the complete soil profile to reach the natural drainage area. This will reduce the soil-water contact time and also reduce the amount of the soil profile which will be subject to leaching.

Future control of the quality of irrigation return water will require better water management by the irrigator. By eliminating surface return flow the problem of increased sediment, pesticides and herbicides, phosphate, and heavy metal concentrations will be minimized. Subsurface return flows, while more difficult to control, can be reduced by better farm management utilizing irrigation scheduling, improved delivery and application methods, such as lined or closed delivery systems, drip and spray irrigation, and more efficient drainage facilities.

A discussion of the impact of TDS concentration increases on other water uses may be found in Appendix I.

Conservation Tillage

A number of alternative systems have been developed over the years to reduce the erosion potential of tillage. With some systems, a surface configuration is achieved that will retain water and increase infiltration. With others, residue from the previous crop is left on the soil surface to break raindrop impact and reduce the flow velocity of runoff. The conservation tillage system that best fits a farm operation depends on the crops grown, soil characteristics, and climate of the area.

Grassed Waterways

Grassed waterways are natural or constructed outlets, shaped to required dimensions and established with erosion resistant vegetation.

They are used for safe disposal of runoff from fields. The most satisfactory location for a waterway may be a well-vegetated natural draw.

Stripcropping

Stripcropping is practiced as a means of reducing erosion on tilled soils. The intent is to break the length of the slope into segments by laying out strips across the natural slope of the land. Strips of close-growing crops or meadow grasses are planted between tilled row crop strips to serve as sediment fillers. The practice effectively reduces the velocity of the water as it leaves the tilled area.

Contouring

Performing tillage operations on the contour, in a direction perpendicular to the slope of the land, provides more protection from water erosion than tilling parallel to the slope. The contour rows collect and hold water during rainstorms and reduce runoff velocity, thereby increasing the time for infiltration and reducing erosion.

Terraces

Terracing is generally applied to fields where contouring, stripcropping, and tillage operations do not offer adequate soil protection. Terraces break the length of the slope into shorter segments. The volume and velocity of water are effectively reduced when one or more terraces intercept the flow of runoff.

Diversions

Diversions are large, individually designed terraces, constructed across the slope to intercept and divert excess funoff to a stable outlet. They are generally constructed above croplands, gully headcuts, or other critical erosion areas. By reducing the volume of runoff entering the problem area, soil erosion is reduced.

Other Practices

Other cropland erosion control practices include crop rotation, use of cover crops, and various structural alternatives, such as settling basins, and special spillways, inlets and flumes.

Range and Pasture Management

Lands used for grazing are characterized by a diversity of climate, topography, soils, vegetative type, and vegetative condition. This diversity, coupled with varying intensities of livestock use, creates the potential for varying degrees of water erosion.

Prevention and control of erosion from grazing land is accomplished through management practices that control the intensity of livestock use, and/or increase the density and productivity of the vegetation. Overgrazing results in soil structure changes because of soil compaction and attendant reduction of soil permeability. It also changes the density, vigor, and species composition of vegetation and reduces the protective soil cover afforded by vegetation.

Grazing management practices that restrict livestock use to the carrying capacity of range or pasture reduce erosion and sedimentation. Some of these practices are:

1. Rotation grazing - permits intensive use of fields on an alternating basis, thereby encouraging vegetation recovery.

2. Water supply dispersal - provides better distribution of livestock and reduces overgrazing in the vicinity of water supplies.

3. Seasonal grazing - utilizes the most productive period for a particular vegetation and permits recovery and reseeding.

4. Range revegetation - increases the density, vigor, and desirable composition of the vegetative cover.

Feedlot Waste Control

In recent years many sophisticated methods of waste control have been tried in the feedlot industry (e.g. aerobic-anaerobic lagoons, oxidation ditches, rotating biological disk units), but none will consistently produce effluent that will meet receiving water and discharge standards in an economical manner. Most authorities have concluded that the cheapest and simplest method of feedlot waste control is to prevent any discharge from the facility except under catastrophic weather conditions.

"No surface discharge" can be achieved under most circumstances by diverting all extraneous runoff away from the lot so that only the precipitation falling into the facility has to be retained. The runoff to be retained is then handled by installing adequately-sized retention facilities (e.g. basins, ponds, terraces, closed irrigation canals) directly below the lot to collect all waters draining from the feedlot itself. In the NGP the most common control systems are the drainageway debris basin and holding pond system equipped with dewatering pump for disposal by flood irrigation or an evaporative lagoon system.

Most states, where feedlots are prevalent, have developed guidelines for design and operation of the waste control facilities. The criteria for design are relatively straightforward. The most common basis for sizing the runoff retention facilities is a rainfall duration of 24 hours having a 10-year reoccurrence probability. System design is dependent primarily on climatic conditions, such as daily, seasonal, and annual rainfall, annual evaporation rates, and frost-free periods suitable for dewatering; then dependent upon topographical conditions, such as the distance from receiving waters.

Where pollution control is now becoming a major factor in the siting of feedlots, the dryer climate of the NGP may encourage an expansion of the feedlot industry. The amount of rainfall directly influences the cost of runoff controls.

VI-C "Domestic" Wastewater Treatment

All municipalities within the study area provide at least partial treatment of sewage. For the purposes of this report, the types of waste treatment may be divided into three categories: primary treatment, secondary treatment, and advanced waste treatment. The term primary treatment refers to those methods which remove a part of the suspended and floating solids. Secondary treatment is the stabilization of the organic matter, i.e., the satisfying of the oxygen demand. Advanced waste treatment may include any one of a number of chemical, physical or biological processes. Advanced waste treatment may be utilized to reduce the amount of nutrients, primarily nitrogen and/or phosphorus, in the discharge.

In addition to these three treatment categories, disinfection of the treatment plant effluent may be utilized to reduce the number of pathogenic organisms in the waste treatment plant discharge. Chlorine residuals may thus exist in the discharges.

Most municipalities within the Northern Great Plains study area now utilize some type of secondary treatment process. There are few tertiary treatment plants in operation in the study area. The secondary waste treatment plants employed within the study area fall into two categories; mechanical waste treatment and oxidation ponds or lagoons.

Mechanical Waste Treatment Plants

Mechanical waste treatment plants usually consist of primary treatment to remove solid material followed by some type of biological process. The two most common types of biological processes are the activated sludge process and the trickling filter process.

Trickling Filter

The trickling filter is the most widely used biological process in mechanical waste treatment plants. The trickling filter consists of a rock media over which sewage is spread by means of a rotary distributor.

The waste flows by gravity over the stones and into an underdrain system where it is collected and discharged to a final sedimentation tank where the solids are removed. The rocks in the filter provide a surface for a layer of microorganisms which in turn convert the organic material in the sewage into cellular material which is eventually removed in the final sedimentation tank. Oxygen for the organisms is provided by air pumped through the voids in the rock.

Activated Sludge

As the name indicates, this method of waste treatment utilizes a sludge which by aeration has become flocculent and accumulated a large population of microorganisms. The wastewater enters an aeration tank where it is mixed with the activated sludge. This mixture, called mixed liquor, is mixed and aerated by means of diffused aeration, mechanical aerators, or a combination of both. The microorganisms in the mixed liquor stabilize the organic matter in the aeration tank and flow into the sedimentation tank. Sedimentation allows the activated sludge to settle out, producing a clear effluent which contains little organic matter. A portion of the activated sludge is returned to the aeration tank as seed and the remainder is disposed of.

Oxidation Ponds

The oxidation pond or lagoon is the most common method of domestic wastewater treatment utilized within the study area. The oxidation pond is a shallow artificial pond in which wastewater is added, usually at one edge or the middle, and the effluent removed at another edge. The ponds are usually two to four feet deep, the minimum depth being controlled by the depth which will prevent weed growth; usually two feet. The maximum depth is determined by the amount of mixing that is desired.

The oxidation ponds are usually designed such that two or more ponds operate in series. The heavy solids are removed in the first pond and the organic matter is stabilized by the bacteria present in each pond. The quality of the discharge from each pond becomes progressively better. The last pond in the series may continuously discharge to the receiving water or may be designed to retain the wastewater for a certain period of time so that there will be only two or three discharges per year.

Aeration of the ponds is a combination of surface aeration resulting from wind action and microbial action, with algae providing oxygen to the bacteria. Mechanical aeration is also utilized to supplement natural aeration.

During the winter months ponds are usually covered by ice. The ice cover eliminates surface aeration and the cold water temperature reduces the biological activity. As a result, the quality of the effluent tends to deteriorate.

It is during this period that the wastewater is usually retained within the final pond and there is no discharge to the receiving water.

Performance Characteristics

The trickling filter treatment process is capable of producing an effluent with a 5-day BOD in the range of 20 to 40 mg/l if properly operated. The process is somewhat sensitive to temperature with poorer BOD removals occurring during the winter months when the temperature of the sewage is lower.

The activated sludge process is capable of a higher degree of treatment if properly designed and operated. The 5-day BOD in the effluent of an activated sludge plant is usually less than 30 mg/l with values of 10 mg/l to 15 mg/l not uncommon.

Both processes require well trained operators to achieve good waste treatment. The main advantage to the mechanical treatment plants is that relatively small land areas are required for the treatment facilities.

The quality of the effluent from oxidation ponds can be highly variable. However, a properly designed oxidation pond can produce an effluent with a 5-day BOD in the range of 20 to 40 mg/l.

The chief advantage of the oxidation pond method of waste treatment is that operational problems are minimized and a skilled operator is not required. Operation consists mainly of eliminating emergent vegetation, and keeping the embankments in good repair. The disadvantages are the large land areas that are required for the ponds and the fact that the effluent may be of poor quality during periods of ice cover.

VI-D Coal Conversion Plants

The single and most important measure available to mitigate potential water quality impacts arising from conversion of coal to energy is water reuse and conservation. These aspects were treated in Chapter II.

CHAPTER VII

AREAS WHERE ADDITIONAL DATA/ANALYTICAL TOOLS ARE NECESSARY

There are many questions concerning water quality in the NGP, and how it can be expected to change as development occurs, that cannot be answered with the data and analytical tools that are available today. Further, in areas where preliminary analysis of impacts is possible, more accurate and more refined estimates would be possible with additional research. The purpose of this chapter is to briefly discuss those areas where the Water Quality Subgroup feels additional data and/or analytical tools are necessary before an adequate informational and analytical framework will be available for decision makers in the NGP relative to water quality.

VII-A Surface Water Quality and Hydrologic (Flow Cross Section) Network

Water quality data have not been collected to any degree which allows either accurate characterization of ambient quality or prediction of changes in quality as a result of changed use of water. Data deficiencies are attributable to (1) short periods of record, (2) sparse distribution of stations, and (3) limited chemical, biological, or physical measurements of presently occupied stations. The USDI-Geological Survey and EPA have initiated a somewhat more extensive surface water quality network in the States of Wyoming, North Dakota, and Montana as of the Spring of 1974. However, the sampling frequencies and 1-year period of record are insufficient to serve as a basis from which predictions can be made since the vagaries in flow from one year to the next may not be represented in the one year of data. Further, the ongoing analyses will be reconnaissance in nature due to the lack of information available on the importance of trace elements. With this and other ongoing research, the most important trace elements may not be identified until we are well into the surface water sampling operation and adequate baseline data for as yet unmeasured parameters would have to be acquired in subsequent sampling.

The gathering of background data cannot continue forever, both because of ensuing development and because of a need to avoid studies with indefinite time frames. However, it will be necessary to develop monitoring networks for surface water quality that adequately measure impacts of man's activities. Thus, there is an additional need to design sampling and assay networks that will allow planning and regulatory agencies to detect changes in water quality that may, in turn, affect the aquatic ecosystem.

At a minimum and based on our present knowledge of the importance of water quality parameters, measurements should include daily flow, daily temperature, daily conductance (with reliable conversion factor to total dissolved solids), daily to composited weekly pH, weekly dissolved oxygen with intensive surveys of hourly and daily DO during critical periods, weekly to composite bi-weekly assay of common ions (Ca, Mg, Na, etc.), weekly BOD (or COD or TOC providing interrelationship is determined) with intensive surveys of mixing zones in areas of BOD loadings, bi-weekly to composite monthly assay for "metals" (lead, copper, mercury, aluminum, boron, zinc, selenium, molybdenum, uranium, arsenic, etc.) and for fluorine, ammonia, nitrate-nitrite and phosphorus with intensive surveys of daily concentrations in selected areas. Ideally, the network will be adapted to measure a minimum number of parameters whose selection will be based upon ongoing (present) efforts and new developments that may indicate which variables are most likely to be affected by coal or other resource "development".

VII-B Non-Point Source Pollution in the NGP

Non-point source pollution - diffuse sources emanating from and accelerated by such man-caused factors as strip mining, mining-related activities, construction-related activities, silviculture activities, grazing, road building, etc. - and its control is a problem of great and growing magnitude for the Northern Great Plains area. Control of non-point pollution will play an increasingly prominent role in environmental protection and pollution control efforts for the area.

At present, there is much less known and the extent and magnitude less well understood about non-point source pollution than there is for point sources. In general terms, however, it is known that sediment constitutes the greatest load of any pollutant in the surface waters of the nation - across the nation, sediment loading in streams is 500 to 700 times greater than that from domestic sewage discharge. Given the nature of the resources - physical, biologic, climatologic - in the NGP area and the nature of the land uses and human activities projected and already occurring in the area, it is obvious that sediment and erosion will be a very significant factor in environmental degradation of the area. Other types of non-point pollution can be expected to increase in like manner.

Non-point pollution control efforts will necessarily be more prevention or source control oriented than treatment of pollutant oriented. The obvious and major research and development efforts aimed at understanding and controlling non-point problems would include: delineation of the geographical location and magnitude of the problem; better correlation of problems with sources, man-caused and natural-caused; development of loading values/functions for NPS and land use complexes; development of basin load allocation models capable of using NPS loading inputs; evaluation of available source control options under representative conditions; development of new cost/effective source control systems necessary to meet applicable water standards; and a better understanding of in-stream damages and detriments attributable to NPS factors.

VII-C Identification and Quantification of Source-Terms for Water Quality Predictions Related to Coal "Development"

There are no reliable or documented estimates of what changes in water quality parameters may occur if new coal-fired energy conversion facilities are installed in the Northern Great Plains. The inability to estimate changes in water quality is not only a function of the lack of ambient surface water and ground water quality data, but also of the lack of definition of the amount and quality of water discharges from somewhat unique conversion processes such as coal gasification. Further, we lack information regarding the sediment yield from mined areas at various stages of development. As a result, it is difficult to predict changes in total dissolved solids concentrations and/or total suspended solids resulting from discharges.

While this need is a part of a complex situation which includes the need to accurately identify the quality of water conveyed to the conversion facilities, types of conversion processes, including cooling, and true water needs, disposal techniques, and shallow hydrologic regimes, the specific need herein described is to quantify water uses and discharges with measurement of any changes in water quality in operations such as mines, urban centers, or gasification plants. EPA has initiated an evaluation of water uses, needs, and economics through its Corvallis National Environmental Research Center. However, the effort is not yet extensive enough to cover coal strip mines and/or coal gasification plants with any high degree of certainty. The question of the impact on water quality of urban non-point sources is also not adequately addressed as yet.

VII-D Water Use Requirements and Alternatives for Coal "Development"

It appears appropriate for planners and regulatory agencies to know, with relative certainty, water use requirements for various stages of coal development, including mining, coal-fired power plants, coal gasification plants, in-situ conversion processes, urban centers, land rehabilitation, etc. This relates to the aforementioned need to quantify source terms for water quality predictions. However, it relates to all operations related to coal development rather than just those for which there is little knowledge regarding changes in water quality. For example, there is no basis upon which anyone can specify the minimum amount of water necessary to operate a 1000 Megawatt coal-fired plant or a 250 x 10^6 SCF/D coal gasification plant. Assessments of what improvements in technology might lower the present requirements are only started. An objective will be to show how maximum water reuse may be achieved. The objective of fulfilling the need is to develop a methodology that allows the decision-makers to compare water use alternatives for proposed plants and to include in the comparisons economic tradeoffs.

VII-E Development of Modelling Tools for Surface Water Quality Projections

Water quality modelling has not been attempted in a comprehensive fashion for the areas such as the Northern Great Plains where data describing ambient quality and interrelationships between quality, flow and water uses are scarce. Existing modelling or predictive methodologies must be evaluated and modified if appropriate. New methodologies may have to be devised. The outcome is to be the designation of the best model(s) with subsequent field verification and collection of pertinent input data. The analysis will result in a method manual which described in detail the models available, the limitations and advantages, the sensitivities of the appropriate models to changes in key parameters and to data deficiencies. From this information, the contract monitoring network referred to above in VII-A can be refined.

VII-F Development of Verified Instream Needs for All Streams

Work is under way on the development of a methodology for predicting instream needs in NGP streams, and efforts will soon be under way to field verify this methodology on the Tongue River. The analysis of impacts of coal development must await the outcome of this and related work. A methodology that adequately addresses both the macroscopic and microscopic levels of the ecosystem is required. Upon successful development of the methodology for the Tongue River, application and verification, including a monitoring scheme for collection of data and monitoring impacts, to other streams will be necessary.

VII-G Assessment of Shallow and Deep Ground Water Reserves and the Impact of Coal "Development" on These Resources

There are a number of areas under the subject of ground water that require additional efforts. To date the NGPRP has initiated a reconnaissance effort to enable predictions of the impact of strip mining on the physical and chemical characteristics of the shallow ground water regime. This effort is necessarily site-specific and limited. A comprehensive analysis of the shallow ground water system to enable predictions of potential impacts on the quality and quantity of these waters should be initiated. Leaching studies of spoils materials are appropriate along with microscale investigations of changes in water characteristics with time in the spoil materials of mines.

Deeper ground water resources have been reviewed in only a reconnaissance manner. Drilling programs have not been started. In order to assess the potential for developing (which assumes the simultaneous evaluation of the impacts of developing) deep (Madison) ground water, numerous measurements of aquifer characteristics and water quality are required. Sufficient bases to allow accurate planning of ground water withdrawals are necessary to avoid undue depletions of the ground water reserves.

Shallow aquifer data are needed to permit evaluation of the impact of large (new) reservoirs, primarily those used to cool or evaporate water discharges. For this purpose and others, the data needs include extensive aquifer testing to enable prediction of the reaction of the hydrologic system to new stresses.

VII-H Alternate Siting of Coal Conversion Facilities Near Large Water Bodies

In general, three methods of energy production have been seriously considered in the NGP. Two methods involve coal-fired power plants, the third involves coal gasification. Siting of such plants has followed two lines of thought -- one suggests mine-mouth power plants and coal gasification plants, the other involves transportation of the coal to power plants near electrical demand centers. In both cases water is generally transported to the plants unless the load center lies conveniently near a water supply. The question of interest then is, "Is there a 'halfway point' where coal is transported to a site near large surface water bodies, such as the Missouri River, and electricity (or gas) is then transported some distance to demand centers?" The need for future work obviously includes both a need to assess the physical and ecological impact of the large discharges of heat into such water bodies and the efficiencies of coal and electricity (and gas) transport.

VII-I Leaching Potential of Soils and Spoils Materials Near Coals

The potential impacts of leaching on ground water quality are discussed above. The leaching tests of spoils samples are required to better estimate the potential of spoils to contaminate ground water and to develop appropriate field tests as well as laboratory tests that allow the planner, through mediums including the mining plan, to avoid highly detrimental overburden. If appropriate, such tests may lead to identification and testing of methods to limit leaching of potentially harmful elements. EPA is planning to support a reconnaissance effort in this area during 1974.

VII-J Analysis of Impacts of Transbasin Diversions

There is a need for considerable analysis on the potential impacts on the quality of water and the environmental effects in areas of water origin of transbasin diversions. Such transbasin diversion work should address coal slurry pipeline diversions as well as just water diversions. This has not been addressed by the NGPRP to date.

VII-K Identification of Correlations Between Trace Element Content of Surface and Near-Surface Waters, Parent Material, Soils, and Sediment

Identification of correlations between trace element content of surface and near-surface waters, parent material, soils, and sediment. For purposes of land use planning, as well as for identifying and understanding ambient levels of selected trace elements, such as mercury, selenium, molybdenum and arsenic, it is necessary to establish relationships between the concentrations of these elements in these various mediums and weathering/transport mechanisms. The value lies not only in the increased understanding of "background" concentrations vis-a-vis increased concentrations caused by coal "development" but also in the identification of situations where improper land use would cause high concentrations of hazardous elements. EPA is planning to fund a reconnaissance effort in South Dakota in 1974 that approximates the initial phases of this need.

VII-L Effects of Impoundments on Free-Flowing Streams in the NGP

Discussions of impoundments in Chapter IV do not precisely define conditions which will occur in reservoirs constructed in the NGP. Although broad generalizations can be made concerning water quality and algal growth potential, the development of a fishery in a specific reservoir cannot be predicted on the basis of a literature survey. Only field investigations before and after impoundment can accurately describe the changed produced in the plankton, benthos, and fishery.

More research on the impacts of loss of land is necessary. Inundation could destroy essential agricultural land, wildlife and waterfowl habitat, and wild and scenic areas along impounded streams. Field surveys should be conducted to determine what types of land use practices would be destroyed by impoundments in the NGP.

APPENDICES

I. Water Quality Criteria

II. Supplementary Material for Section I-C.4

III. Questions Concerning Indian Water Rights

IV. A Discussion of Reservoir Limnology with Special Reference to Proposed Reservoirs in the Northern Great Plains

V. An Investigation of the Physical Thermal Effects of Once-Through Cooling for Steam Electric Plants on the Upper Missouri River

VI. Reconnaissance Effort to Quantify Distribution of Trace Elements in Soil, Sediment, and Surface Water of the Missouri River Basin, Western South Dakota

APPENDIX I

WATER QUALITY CRITERIA

The increased concentration of dissolved solids in natural waters as a result of man's activities can be detrimental to using the water for various purposes. Such purposes include irrigation, livestock watering, industrial cooling and process water, and maintenance of aquatic life. Criteria for dissolved solids have been proposed by the Environmental Protection Agency for various uses of water, although limited knowledge about the long and short term effects makes these judgements difficult.

Water used for irrigation which has a relatively high concentration of dissolved solids can affect plant growth, depending primarily upon water management, the type of crop, the soil composition, and the constituent salts. If the soils upon which irrigated crops are grown have a relatively high content of leachable salts in the root zone, the salinity of the applied water will need to be considerably less in order to be used for irrigation. The salinity tolerance for some irrigated crops that are grown in the Northern Great Plains Region are listed in Table App-I-1. The salinity concentrations listed in this Table are saturation extract (EC_e) values which are determined by a scientific procedure of mixing demineralized water with soil, filtering off the water, and measuring the electrical conductivity of the leached salts. The salinity of irrigation water applied to the crops cannot be compared with the saturation extract values because of the leachable salts contained in the soil.

EPA's proposed criteria for total dissolved solids in irrigation waters are limits of 2,000 to 5,000 mg/l for tolerant plants in permeable soils or 500 to 1,000 mg/l for sensitive crops. TDS concentrations in excess of 1,000 mg/l adversely affect many crops, unless careful water management is practiced. Table App-I-2 gives recommended guidelines for salinity (TDS) in irrigation water.

In addition to the effect of salinity on plant growth, individual ions may cause growth reductions. The presence of relatively high concentration of sodium in irrigation waters, as a portion of the TDS concentration, can affect crops. Depending on the soil composition, sodium can cause a decrease in soil permeability resulting in a surface crust formation that deters seed germination and emergence. Sodium is also known to have a toxic effect on certain plants.

Trace elements are presented in irrigation water and can also affect plant growth. In many cases, soild have high capacities to react with trace elements. Therefore, irrigation water containing toxic levels of trace elements may be added for many years before a steady state is approached. Thus, a situation exists where toxicities may develop in years, decades, or even centuries from the continued addition of pollutants to irrigation waters. The time would depend on

Table App-I-1(1)

Crop	Salinity (mg/1)(2)		
	10% Yield Reduction	25% Yield Reduction	50% Yield Reduction
Hay			
Burmuda Grass	8,700	10,700	12,000
Barley Hay	5,300	7,300	9,300
Alfalfa	7,000	3,300	5,300
Barley	8,000	10,700	12,000
Sugar Beets	6,700	8,700	10,700
Wheat	4,700	6,700	9,300
Oats	4,700	6,700	9,300
Rye	4,700	7,300	9,300
Corn	3,300	4,000	4,700
Dry Beans	1,300	2,000	2,700
Potatoes	1,300	2,000	3,300

(1) Water Quality Criteria, 1972, National Academy of Sciences

(2) Assumes 1 mmhos/cm (ECe) = 666 mg/l (TDS)

Table App-I-2(1)

Recommended Guidelines for Salinity in Irrigation Water

Classification		EC mmhos/cm
Water for which no detrimental effects are usually noticed	500	0.75
Water that can have detrimental effects on sensitive crops	500 - 1,000	0.75 - 1.50
Water that can have adverse effects on many crops; requires careful management practices	1,000 - 2,000	1.50 - 3.00
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000 - 5,000	3.00 - 7.50

(1) Water Quality Criteria, 1972, National Academy of Sciences

soil and plant factors as well as on the concentration of trace elements in the water. Some suggested maximum trace element concentrations for irrigation waters are shown in Table App-I-3.

Table App-I-2 gives recommended guidelines for salinity in water to be used for irrigation.

For the most part these recommended maximum concentrations correspond to the EPA proposed criteria with minor exceptions for Boron, Fluoride, Lithium, and Vanadium and Zinc where no criteria were proposed.

It is known that excessively saline waters can cause physiological upset or death of livestock. For this reason EPA has proposed a maximum acceptable salinity level for livestock drinking water of 3,000 mg/l. While some minor physiological upset may result from waters with salinity near this prescribed limit, economic losses or serious physiological disturbances should rarely, if ever, result from their use.

As in irrigation, trace elements can also be toxic to livestock. The proposed EPA criteria for trace elements in livestock drinking water are given in Table App-I-4.

Water supplies for certain industrial uses may require removal of dissolved solids to within acceptable limits. For this reason increasing salinity concentrations become economically important to these industries. Requirements in the concentration of total dissolved solids for some industrial water uses are shown in Table App-I-5.

The quantity and quality of dissolved solids are major factors in determining the variety and abundance of plants and animals in an aquatic system. They serve as nutrients in productivity, osmotic stress, and direct toxicity. A major change in quantity or composition of total dissolved solids changes the structure and function of aquatic ecosystems.

Concentrations of dissolved solids affecting freshwater fish by osmotic stress are not well known. The upper limit may range between 5,000 and 10,000 mg/l depending on species and prior acclimatization. The literature indicates that concentrations of TDS that cause osmotic stress in adult fish are higher than the concentrations existing in most fresh waters of the United States.

The Environmental Protection Agency's recommendation concerning TDS effects on the aquatic ecosystem states that: "Total dissolved materials should not be changed to the extent that the biological communities characteristic or particular habitats are significantly changed. When dissolved materials are altered, bioassays and field studies can determine the limits that may be tolerated without endangering the structure and function of the aquatic ecosystem."[1]

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[1] Proposed Criteria for Water Quality - Volume I, page 137, EPA, October, 1973.

Table App-I-3(1)

Recommended Maximum Concentrations of Trace Elements in Irrigation Waters

Element	For waters used continuously on all soil mg/l	For use up to 20 years on fine textured soils of pH 6.0 to 8.5 mg/l
Aluminum......	5.0	20.0
Arsenic.......	0.10	2.0
Beryllium.....	0.10	0.50
Boron.........	0.75	2.0
Cadmium.......	0.010	0.050
Chronium......	0.10	1.0
Cobalt........	0.050	5.0
Copper........	0.20	5.0
Fluoride......	1.0	15.0
Iron..........	5.0	20.0
Lead..........	5.0	10.0
Lithium.......	2.50	2.5
Manganese.....	0.20	10.0
Molybdenum....	0.010	0.050
Nickel........	0.20	2.0
Selenium......	0.020	0.020
Tin..........	....	....
Titanium......	....	....
Tungsten......	....	....
Vanadium......	0.10	1.0
Zinc..........	2.0	10.0

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(1) Water Quality Criteria, 1972, NAS

Table App-I-4(1)

Proposed Trace Element Criteria for
Livestock Drinking Water

Element	Maximum Acceptable Concentration (mg/l)
Aluminum	5.0
Arsenic	0.2
Beryllium	none
Boron	5.0
Cadmium	0.05
Chronium	1.0
Cobalt	1.0
Copper	0.5
Fluorine	2.0
Iron	none
Lead	0.1
Manganese	none
Mercury	0.001
Molybdenum	none
Selenium	0.05
Vanadium	0.1
Zinc	25.0

(1) Proposed Criteria for Water Quality, Vol. 1, 1973, EPA

Table App-I-5(1)

TDS Requirements of Some Industrial Water Uses

Water Use	Concentration Not Normally Exceeding (mg/1)
Industrial Boiler Feedwater	
Low pressure	700
Intermediate pressure	500
High pressure	200
Electric Utilities	
Boiler Feedwater (1,500-5,000 psg)	.5
Cooling Water	
Once through	1,000
Make up	500
Canned, Dried, Frozen Fruits and Vegetable Industry	500

(1) Water Quality Criteria, 1972, WAS

APPENDIX II

SUPPLEMENTARY MATERIAL FOR SECTION I-C.4

II-I	Universal Soil Loss Equation
II-II	References for Simulation Models and Prediction of Environmental Effects Due to Sedimentation and Erosion
II-III	Sediment Yield and Reservoir Sediment Deposition Surveys
II-IV	Gully or Channel Erosion Sediment Yield
II-V	References on Subsurface Flow-Water Quality Modelling
II-VI	Sediment Control Structure Design

Appendix II-I

Universal Soil Loss Equation

The equation is:

$$A = RKLSPC$$

where

A = average annual soil loss in tons/acre estimated by the equation

R = the rainfall factor or rainfall - erosion index (EI)

K = the soil erodibility factor

LS = the combination of factors for length and steepness of slope

P = erosion control practice factor

C = the cropping and management factor

In applying the soil loss equation, local and seasonal variations in several of the factors must be accounted for, particularly R, P and C. Before applying the equation, which should be done for each month of the year, the user should consult local personnel of the U.S. Soil Conservation Service for advice and interpretation on representative values for the various factors.

Following are several figures and tables which allow determination of the values of factors.

The first figure (App-II-I-1) represents the seasonal cumulative distribution of the rainfall factor (R) and clearly shows the effect of snowmelt and spring and summer rainfalls.

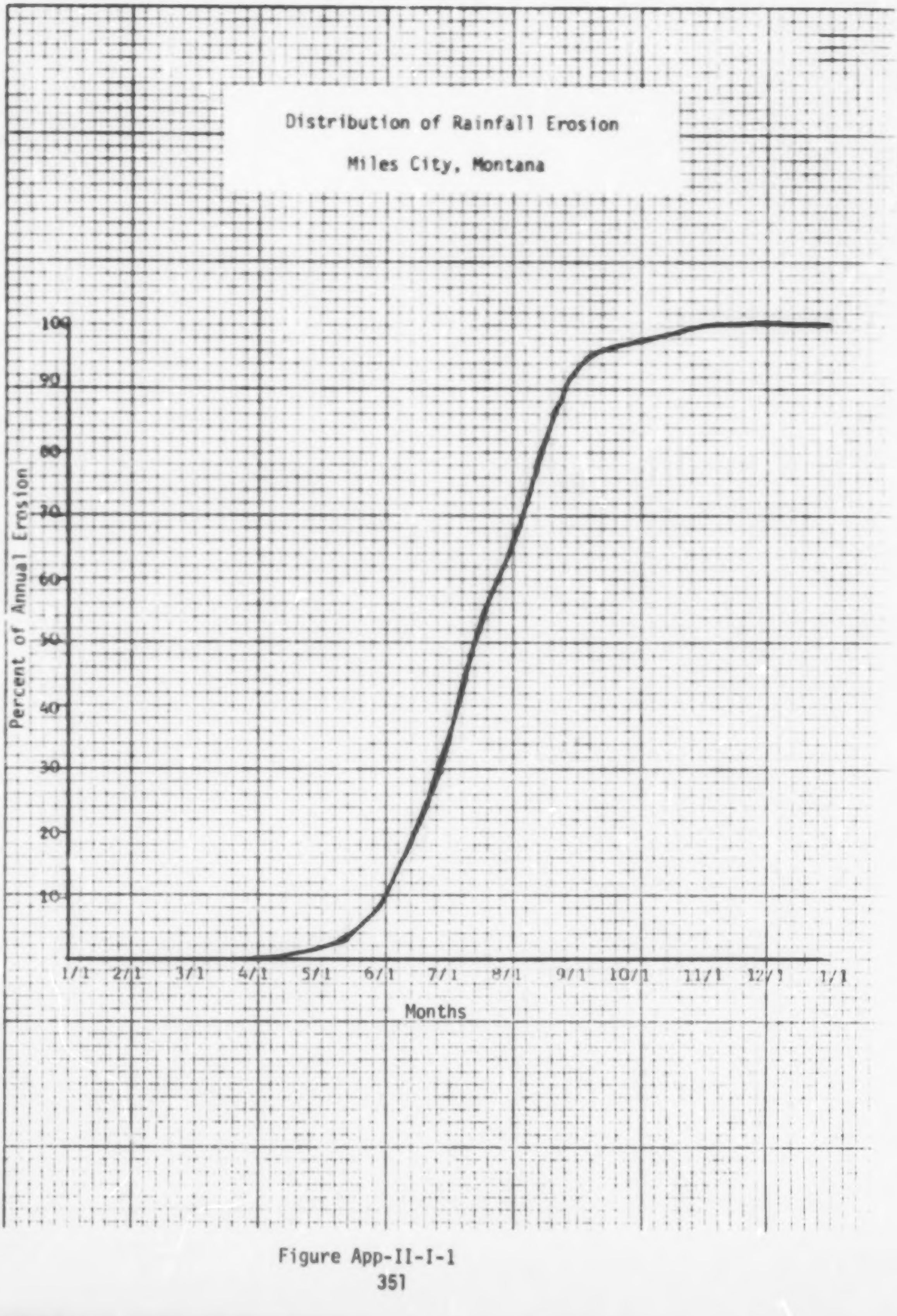
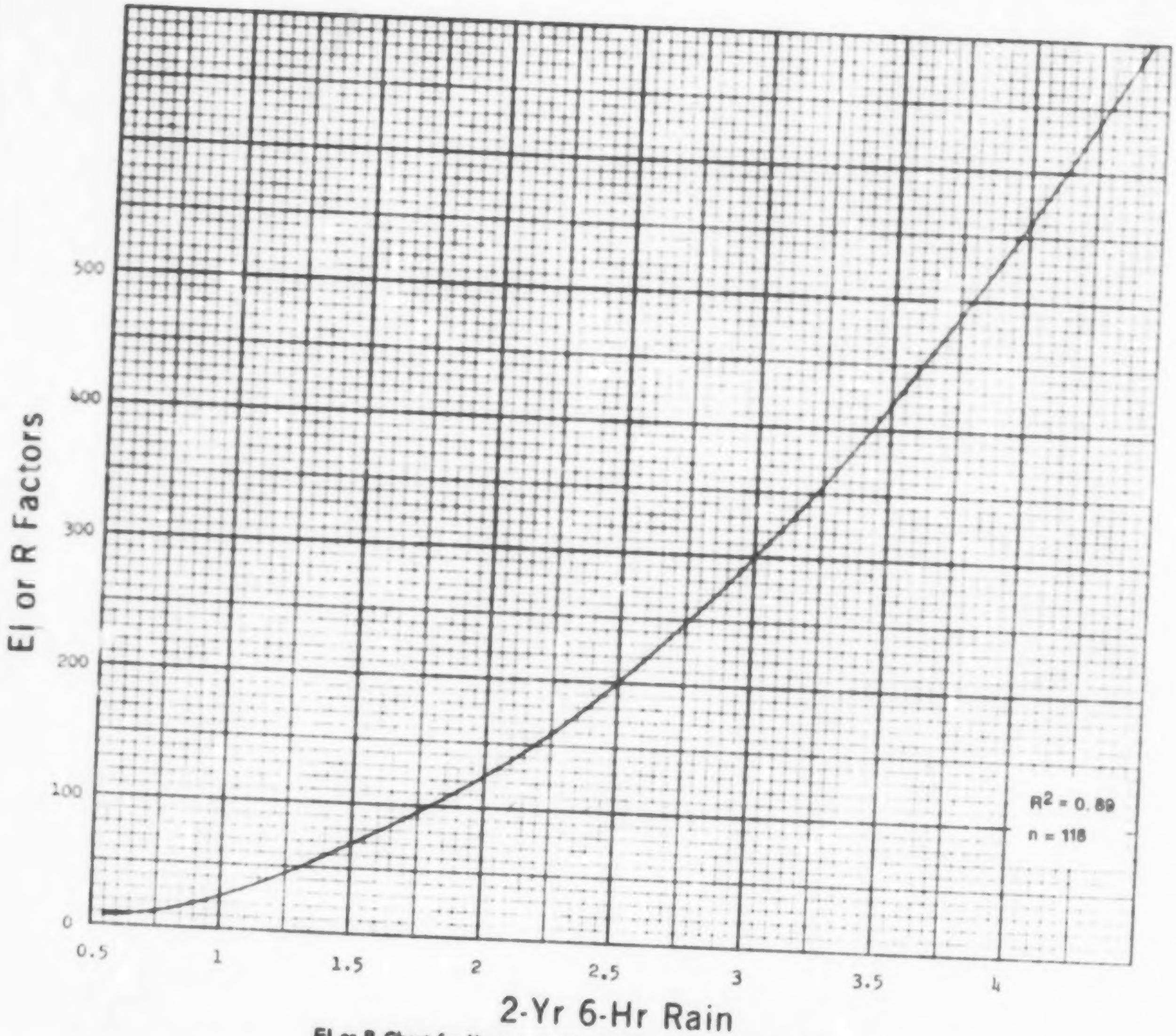


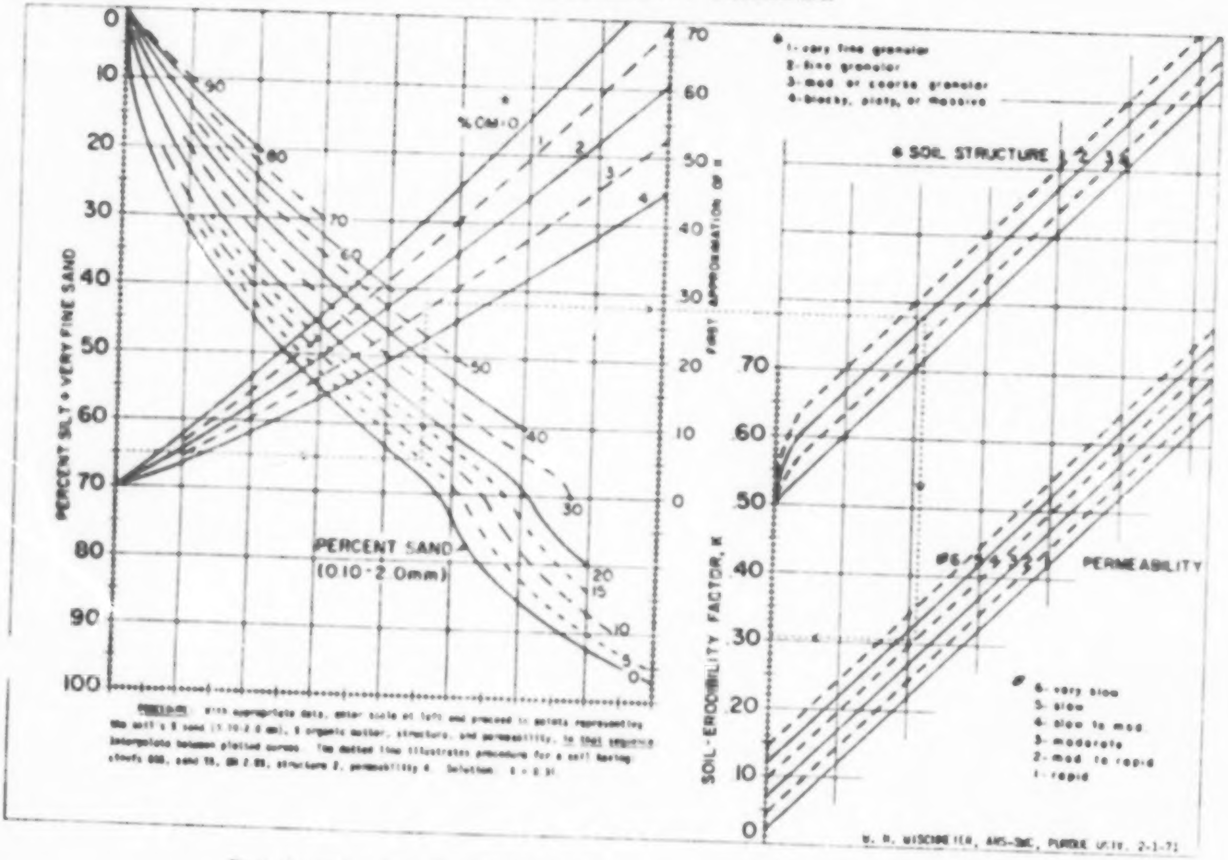
Figure App-II-I-1



El or R Chart for Nonorographic Rainfall Areas in States of SCS – West Region

Figure App-II-I-2

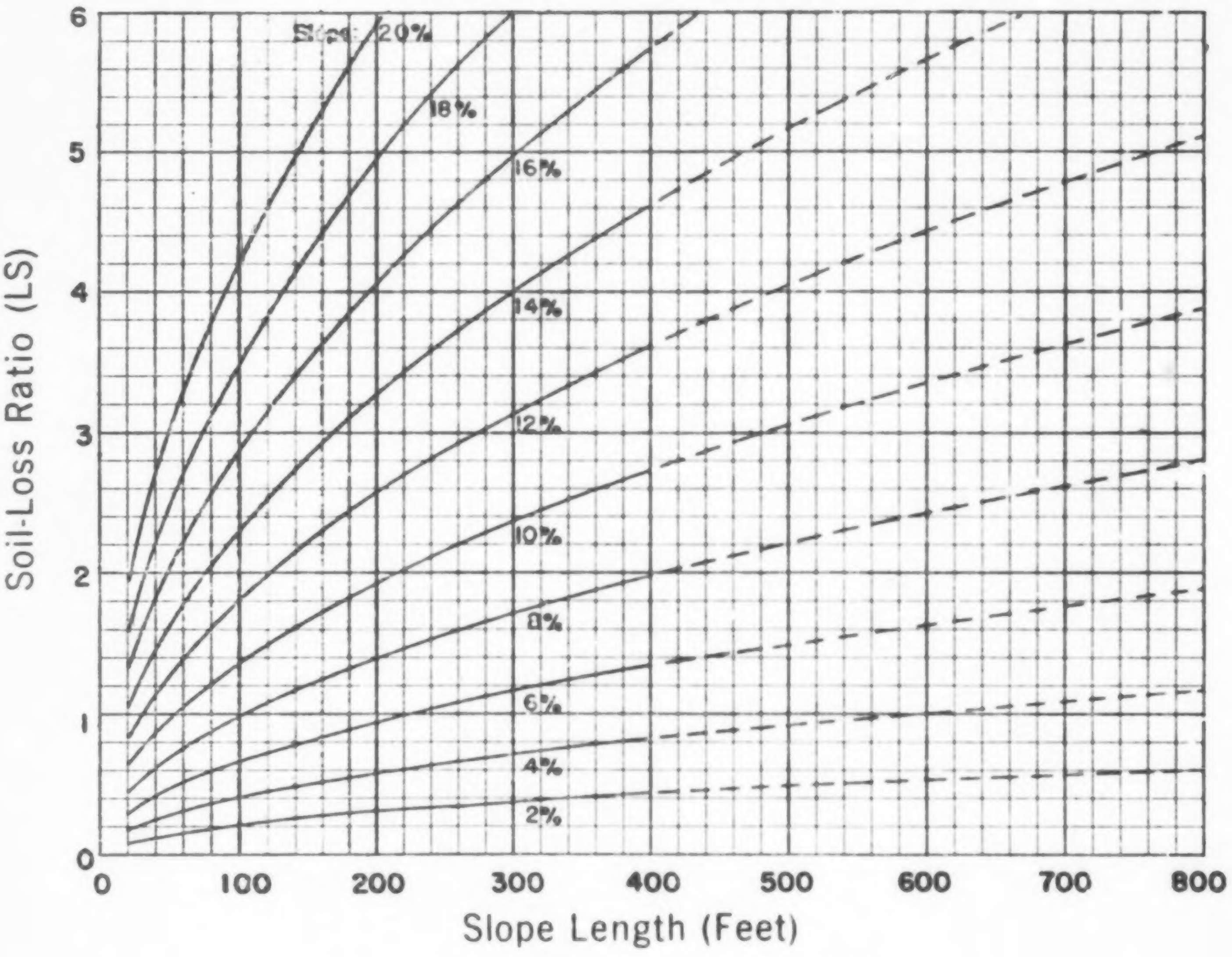
SOIL ERODIBILITY NOMOGRAPH



Reprinted from the Journal of Soil and Water Conservation
September-October 1971, Volume 26, Number 5

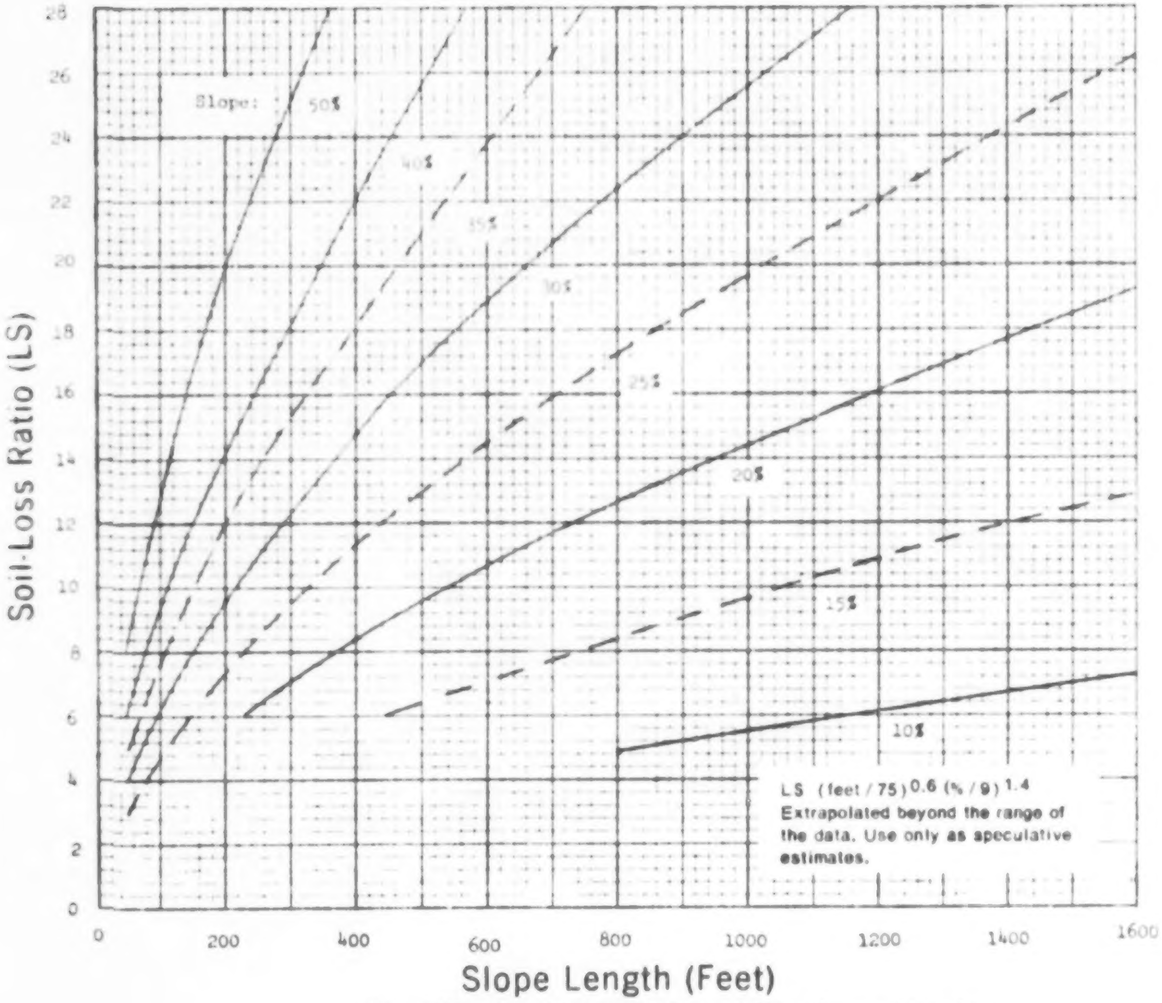
Figure App-II-I-3

* %OM means percent organic matter



Slope – Effect Chart (Topographic Factor, LS).

Figure App-II-I-4



Slope – Effect Chart (Topographic Factor, LS) for Slopes and Lengths Exceeding Those in Figure II-I-4

Figure App-II-I-5

Table App-II-I-1

"C" Values for Permanent Pasture, Rangeland, and Idle Land[1]

Vegetal Canopy			Cover That Contacts the Surface					
Type and Height of Raised Canopy[2]	Canopy Cover[3] %	Type[4]	Percent Ground Cover					
			0	20	40	60	80	95-100
Column No.:	2	3	4	5	6	7	8	9
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or bushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

1/ All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists.

2/ Average fall height of waterdrops from canopy to soil surface: m = meters.

3/ Portion of total-area surface that would be hidden from view by canopy in a vertical projection, (a bird's-eye view).

4/ G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.

W: Cover at surface is mostly broadleaf herbaceous plants (as weeds) with little lateral-root network near the surface, and/or undecayed residue.

Table App-II-I-2

"C" Factors for Woodland

Stand Condition	[1] Tree Canopy % of Area	[2] Forest Litter % of Area	[3] Undergrowth	"C" Factor
Well Stocked	100-75	100-90	Managed[4] Unmanaged[4]	.001 .003-.011
Medium Stocked	70-40	85-75	Managed Unmanaged	.002-.004 .01-.04
Poorly Stocked	35-20	70-40	Managed Unmanaged	.003-.009 .02- .09[5]

---

[1] When tree canopy is less than 20%, the area will be considered as grassland, or cropland for estimating soil loss. See Table 1.

[2] Forest litter is assumed to be at least two inches deep over the percent ground surface area covered.

[3] Undergrowth is defined as shrubs, weeds, grasses, vines, etc., on the surface area not protected by forest litter. Usually found under canopy openings.

[4] Managed - grazing and fires are controlled.
Unmanaged - stands that are overgrazed or subjected to repeated burning.

[5] For unmanaged woodland with litter cover of less than 75%, C values should be derived by taking 0.7 of the appropriate values in Table 1. The factor of 0.7 adjusts for the much higher soil organic matter on permanent woodland.

Erosion Control Practice Factor - P

Data from actual research measurements were the basis for developing these factors.

Slope	Up & Down Hill	Cross Slope Farming Without Strips	Contour Farming	Cross Slope Farming With Strips	R G M	Contour 1/ Strip-Cropping
2.0-7	1.0	.75	.50	.37	.35	.25
7.1-12	1.0	.80	.60	.45	.42	.30
12.1-18	1.0	.90	.80	.60	.56	.40
18.1-24	1.0	.95	.90	.67	.63	.45

1/ Refers to equal width of strips with row crop strips alternating with sod or meadow crop strips.

Table App-II-I-3

Appendix II-II

Listed below are several simulation models and references for prediction of the environmental effects on a stream due to sedimentation and erosion:

1. Negev, N., "A Sediment Model on a Digital Computer", Technical Report 76, Stanford University, Stanford, California (March, 1967).
2. Crawford, N. H. and R. K. Linsley, "Stanford Watershed Model IV", Stanford University, Stanford, California, Technical Report 39, (1966).
3. Crawford, N. H., "What is Simulation", *Hydrocomp Simulation Network Newsletter*, Palo Alto, California, August, 1970.
4. Cawood, P. B., R. Thunvile, and L. Y. Nilsson, "Hydrologic Modeling -- An Approach to Digital Simulation", Report 3:4a, Royal Institute of Technology, Stockholm, Sweden (1971).
5. Holtan, H. N., and N. C. Lopez, "USDAHL-73 Revised Model of Watershed Hydrology", *Plant Physiology Report No. 1*, Agricultural Research Service, U.S. Department of Agriculture, (1973).
6. Snyder, W. M., "Developing a Parametric Hydrologic Model Useful for Sediment Yield", *Proc. of Sediment Yield Workshop*, USDA Sedimentation Laboratory, Oxford, Mississippi, November, 1972.
7. Woolhiser, D. A., "Deterministic Approach to Watershed Modeling", *Nordic Hydrology II*, pp. 146-166, Munksgaard, Copenhagen, Denmark (1971).
8. Foster, G. R. and L. D. Meyer, "Mathematical Simulation of Upland Erosion Using Fundamental Erosion Mechanics", paper presented at Sediment Yield Workshop, Oxford, Mississippi, November, 1972.

Appendix II-III

Sediment Yield and Reservoir Sediment Deposition Surveys

A. East of Rocky Mountains

When available reservoir sedimentation surveys may be utilized to estimate the sediment delivery ratio (or trap efficiency of a reservoir). The equation to utilize is noted below for estimating sediment yield of an unmeasured watershed based on measurements on a watershed in a similar area (a):

$$S_e = S_m \left(\frac{A_e}{A_m}\right) 0.8$$

where

S = sediment yield

A = drainage area

e = unmeasured area

m = measured area

(a) Strand, R. I., "Bureau of Reclamation Procedures for Predicting Sediment Yield", paper presented at Sediment Yield Workshop, Oxford, Mississippi, November, 1972.

B. Western U.S.

The following equation has been developed (b) for estimating sediment yield in 11 western states of the U.S.

$$\begin{aligned} \log(4.75Y + 100) = {} & 6.21 - 2.19 \log(X_1 + 100) \\ & + 0.06 \log(X_2 + 100) \\ & - 0.02 \log(X_3 + 100) \\ & + 0.04 \log(X_4 + 100) \end{aligned}$$

where Y = sediment yield, (m^3/hectare/year)

X_1 = climate factor

$$= \frac{\text{ave. precipitation, (cm)}}{(0.71\ (\text{aver ann. temp., } ^{\circ}\text{C}) + 12.8)}$$

X_2 = topography factor

$$= \frac{\Sigma \text{ (area of contour interval x \% slope)}}{\text{total area}}$$

X_3 = coarseness of soil particles

= 5 of soilpart coarser than

1 mm in top 5 cm of soil

X_4 = soil aggregation index

= % of day size particles 2u or

finer in top cm of soil

Note that the above equation and the accompanying nomograph (Figure App-II-III-1) do not include channel erosion.

(b) Flaxman, E. M., "Predicting Sediment Yield in Western U.S.", paper presented at Sediment Yield Workshop, USDA Sedimentation Lab., Oxford, Mississippi, November, 1972.

C. General

Trap efficiencies can be independently calculated based on sediment trap data from reservoir studies performed by the Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Department of Agriculture Soil Conservation Service or the U.S. Geological Survey as appropriate and where available. Sediment yield is defined by the following equation:

$$Y = E\ (D)$$

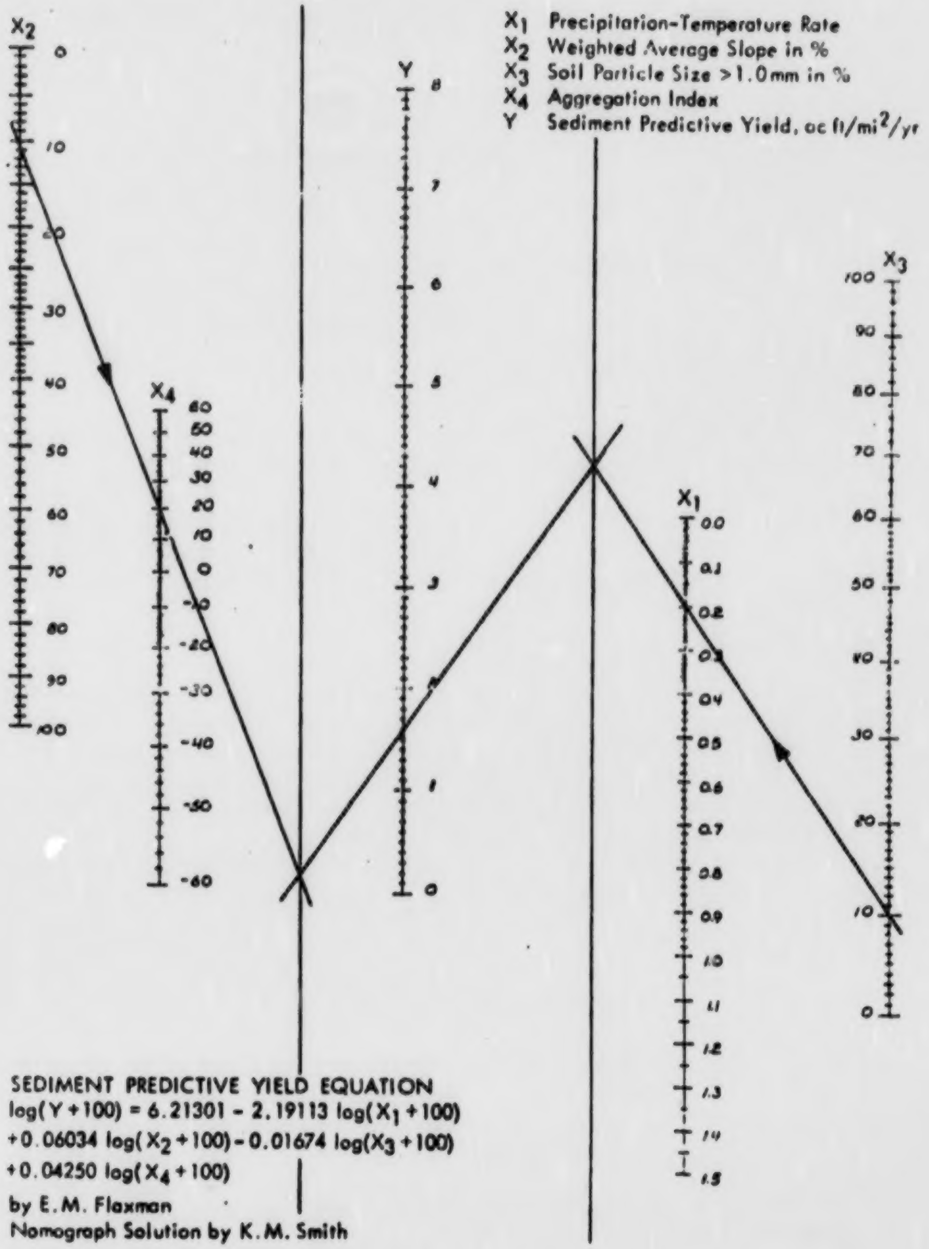
where

Y = sediment yield

E = gross erosion (sheet and rill erosion plus channel erosion)

D = sediment delivery ratio

Figure A-II-III-2 may be used to obtain trap efficiencies from annual inflow data.


X_1 Precipitation-Temperature Rate
X_2 Weighted Average Slope in %
X_3 Soil Particle Size >1.0mm in %
X_4 Aggregation Index
Y Sediment Predictive Yield, ac ft/mi^2/yr
X_2
0
10
20
30
40
50
60
70
80
90
100
X_4
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Y
8
7
6
5
4
3
2
1
0
X_1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
X_3
100
90
80
70
60
50
40
30
20
10
0

SEDIMENT PREDICTIVE YIELD EQUATION

$$\log(Y+100) = 6.21301 - 2.19113 \log(X_1+100) + 0.06034 \log(X_2+100) - 0.01674 \log(X_3+100) + 0.04250 \log(X_4+100)$$

by E.M. Flaxman
Nomograph Solution by K.M. Smith

Figure App-II-III-1

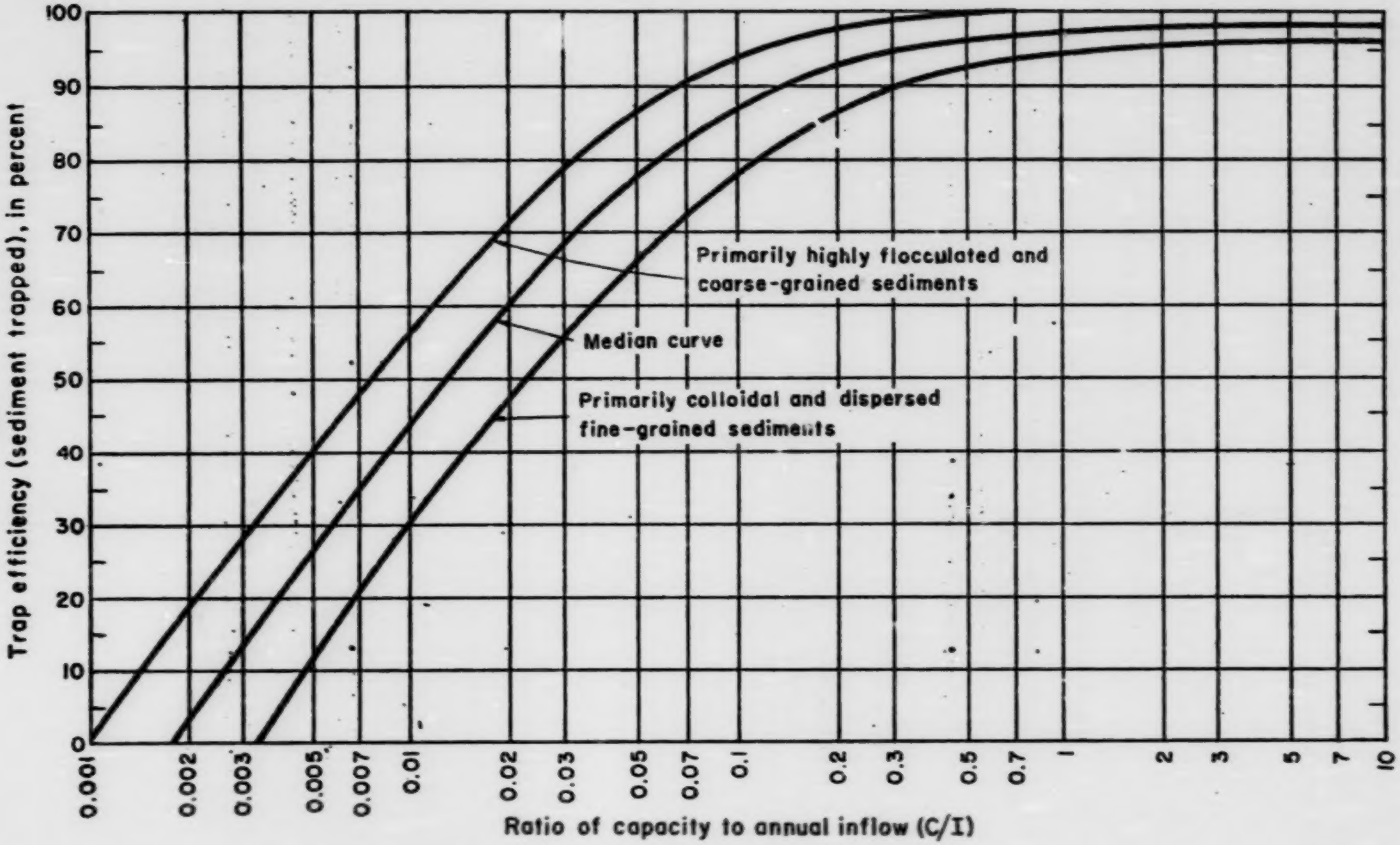


Figure App-II-III-2 Trap efficiency of reservoirs

(REF. U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE,
TECH. RELEASE NO. 12 (REV.), GEOLOGY, JAN 1968)

Appendix II-IV

Gully or Channel Erosion Sediment Yield

The following equation may be utilized to estimate sediment yield from channel erosion.

$$G = F \left(\frac{LgX}{Y}\right)$$

where G = sediment yield from channel erosion

F = a conversion factor for unit consistency

Lg = gully (channel) length

X = average gully cross section eroded in years of the estimate

Y = years of the estimate

Data for the above may be obtained through both field data and aerial photography.

Generalizations as to the relative sediment yield of channel to sheet and rill erosion can be obtained from the state offices of the U.S. Soil Conservation Service.

Appendix II-V

Subsurface Flow/Water Quality Modeling

1. Dutt, G. R., Shaffer, M. J. and Moore, W. J., "Computer Simulation Model of Dynamic Bio Physiochemical Processes in Soils", Technical Bulletin No. 196 of University of Arizona Agricultural Experiment Station (1972).

2. Hanks, R. J. and Bowers, S. A., "Numerical Solutions of the Moisture Flow Equation for Infiltration into Layered Soils", Soil Science Society American Proceedings, Volume 26 (1962).

3. Tanji, K. K., "A Computer Analysis on Leaching of Boron from Stratified Soil Columns", Soil Science, Volume 110 (1970).

4. Tanji, K. K., Doneed, L. K., Ferry, G. V. and Ayers, R. S., "Computer Simulation Analysis on Reclamation of Salt-Affected Soils in San Joaquin Valley, California", Soil Science Society American Proceedings, Volume 36 (1972).

5. Dutt, G. R., "Quality of Percolating Water No. 1 - Development of a Computer Program for Calculating the Ionic Composition of Percolating Waters", Water Resources Center Contribution No. 50, University of California (1962).

6. Dutt, G. R., "Prediction of the Concentration of Solutes in Soil Solutions for Soil Systems Containing Gypsum and Exchangeable Ca and Mg", Soil Science Society American Proceedings, Volume 26 (1962).

7. Tanji, K. K., Doneed, L. D. and Paul, L. J., "III. The Quality of Waters Percolating through Stratified Substrate as Predicted by Computer Analysis", Hilgardia, Volume 38 (1967), 319-347.

8. Thomas, J. L, Riley, J. P. and Isrelsen, E. K., "A Computer Model of the Quantity and Quality of Return Flow", PRWG 77-1, Utah State University, Logan, Utah.

9. Hyatt, M. Leon, "Modeling Salinity in the Upper Colorado River Basin", Proceedings of National Conference on Managing Irrigated Agriculture to Improve Water Quality, U.S. Environmental Protection Agency and Colorado State University (May, 1972), pp. 215-227.

10. Riley, J. P., Chadwick, D. G., and Bagley, J. M., "Application of Electronic Analog Computer to Solution of Hydrologic and River Basin Planning Problems: Utah Simulation Model II", Utah Water Research Laboratory, Utah State University, Logan, Utah (1966).

Appendix II-VI

Sediment Control Structure Design

The following references are recommended to be consulted in design of appropriate structures:

1. *Sediment Storage Requirements for Reservoirs*, U.S. Department of Agriculture, Soil Conservation Service, Engineering Division, Technical Release No. 12 (Rev.) January, 1968.

2. *Guidelines for Erosion and Sediment Control Planning and Implementation*, U.S. Environmental Protection Agency, EPA-R2-72-015, August, 1972.

3. Various publications of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center.

   (in particular Technical Paper No. 40 and its revision, Technical Paper No. 49 (in-print))

4. Chow, V. T., *Handbook of Applied Hydrology*, McGraw-Hill, New York, 1964.

5. *Design of Small Dams*, U.S. Department of Interior, Bureau of Reclamation, revised edition, 1973.

In addition to the above, the following relationship of design period, design storm return period and probability of not exceeding the design basis is presented:

$$P - 1 - (1 - 1/n)^N$$

where P is the probability of the design return storm (n) occurring at least once in N years. This relationship is presented in Figure App-II-VI-1 and should be used when determining the risk to be taken in design of runoff structures in light of the expected or required structure life.

$P = 1 - (1 - 1/n)^N$

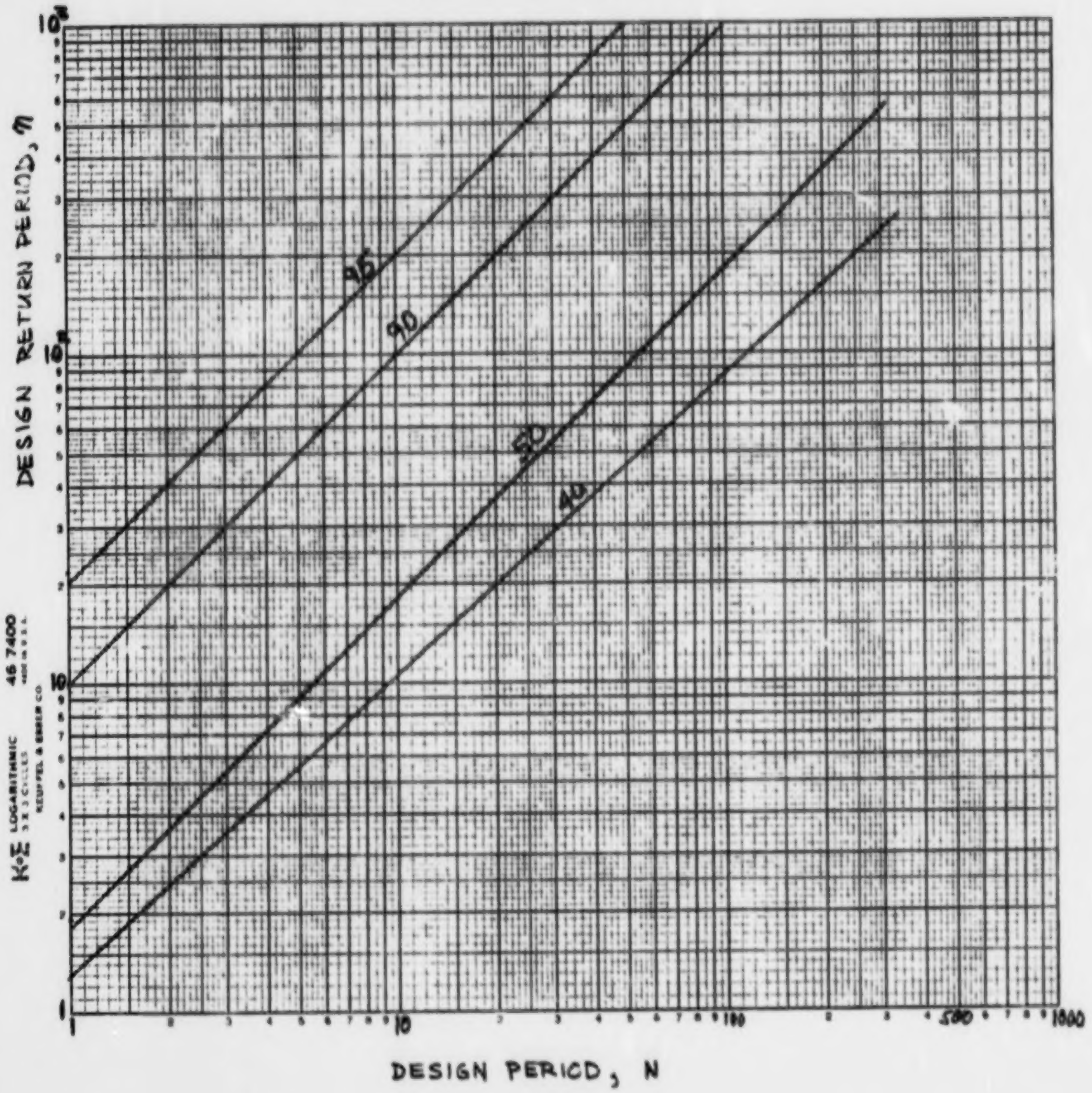


Figure App-II-VI-1

APPENDIX III

QUESTIONS CONCERNING INDIAN WATER RIGHTS

The following is a general discussion of the nature of Indian water rights, and their application to the Indian reservations located in the Northern Great Plains area.

The initial basis for assertion of Indian water rights was founded upon the Supreme Court's ruling in Winters v. United States, 207 U.S. 564 (1908). In Winters, the Court held that although not mentioned in the legal instruments used to establish Indian reservations, there is an implied reservation of rights to the use of the waters which rise upon, traverse, or border upon Indian reservations which may be exercised in connection with Indian lands. While subsequent Federal court decisions have elaborated on the Winters decision[1], the latter remains the primary basis for the assertion of Indian claims to water rights.

In an analysis of Indian reserved rights as developed by Winters and related Federal cases, the three most important questions are: (1) What is the date when title to reserved rights became rested in the Indians, this date may be crucial to the establishment of a priority of use over competing water rights; (2) What is the quantitative measure of such rights; and (3) How do these rights relate to the water allocation systems developed by the states in which the Indian reservations are located (in the present case, the states included within the Northern Great Plains area; Montana, North Dakota, and South Dakota).

1. When Title to Water Rights Becomes Vested in the Indians.

The general rule is that the priority of an Indian water right is set by the date the particular Indian reservation was created. Such water right then becomes appurtenant to the lands within the reservation. Three methods have been utilized to create Indian reservations; prior to 1871 such reservations were created by treaties with the various Indian tribes. By an Act of Congress in 1871 the treaty-making powers of Indians as independent nations were abolished, but treaties made or ratified before the Act were not thereby invalidated or impaired. Of the six reservations located in the Northern Great Plains region, only two were created by treaty[2]. After 1871 the Federal Government dealt with the Indians either by specific Acts of

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[1] For example, although the Court in Winters merely implied that Indian rights are not limited to waters arising on the reservation, this ruling was expressly made in U.S. v. Ahtanum Irrigation District, 236 F.2d 321; Cert. Denied, 352 U.S. 988 (1956).

[2] The Crow and Ceded Area Reservation was created by the Treaty of May 7, 1868; The Fort Berthold Reservation was created by the Treaty of September 17, 1851. The treaty dates would thus become the priority dates for the reserved water rights appurtenant to those reservations.

Congress, which in some cases ratified treaties[1], or by Executive Orders whereby the President set apart public lands for the use of the Indians. In the Northern Great Plains region, three of the reservations have been created by Acts of Congress[2], and one by Executive Order[3].

As stated above, in nearly all of the litigation involving Indian water rights, the date of the "reservation" has implicitly or expressly been regarded as the priority date of the Indians' water rights[4]. However, other theories have been advanced on the priority of Indian rights, although these theories have yet to be litigated[5]. Supporters of Indian rights have argued that, with regard to those reservations created by treaty, the Indians ceded some of their inherent rights to the Federal Government, while retaining others, namely, their water rights[6].

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[1] The Fort Peck Reservation involved the Treaty of December 28, 1887, but consistent with the Government's Indian policy at the time, the treaty specifically provided that its effectiveness was contingent on subsequent approval by an Act of Congress; such a statute was subsequently enacted on May 1, 1888. The date of the statute would thus set the priority date for water rights appurtenant to the Fort Peck Reservation.

[2] The Fort Peck Reservation, by the Act of May 1, 1888 (see Note 3, supra.); The Cheyenne River Reservation, by the Act of March 2, 1889; and the Standing Rock Reservation, also by the Act of March 2, 1889.

[3] The Northern Cheyenne Reservation, by the Executive Order of November 26, 1884.

[4] Winters v. U.S., 207 U.S. 564; Arizona v. California, 373 U.S. 546; U.S. v. Walker River Irrigation District, 104 F.2d 334; Skeem v. U.S., 273 F. 93; U.S. ex.vel. Ray v. Hibner, 27 F.2d 909.

[5] A possible exception is U.S. v. Ahtanum Irrigation District, wherein the Court held that Indian rights to Ahtanum Creek were not tied to the Treaty which created their reservation. However, in this case there was evidence of Indian irrigation operations prior to execution of the Treaty; this probably was a key factor in the Court's decision. The Ahtanum case could be considered to be somewhat atypical, since evidence of Indian irrigation has seldom been involved in cases involving the existence of Indian rights.

[6] In U.S. v. Winans, 198 U.S. 371, the Supreme Court held that the courts will not imply that the Indians have granted the right to their water by a treaty or other conveyance; the water will be reserved for Indian use unless the rights have been clearly surrendered by the Indians.

This argument is thus the converse of the general rule; the treaty was not a grant of rights to the Indians, but rather a grant of rights from them, with a reservation of those rights not granted. Under this theory, the rights which the Indians reserved to themselves are ancestral rights which have existed from time immemorial, and really have no priority date. This theory would not apply to those reservations created by Act of Congress or by Executive Order, since these reservations are essentially withdrawals from the public domain which have been granted to the Indians by the Federal Government. No ancient priority would thus attach to these reservations. It is also questionable whether this theory would apply to nomadic tribes which had been removed from their ancestral lands to remote reservations.

2. What Is the Quantitative Measure of Indian Water Rights.

It is generally recognized that the quantity of water rights accruing to the Indians is not to be measured by the use of the water being made by the Indians at the time of the execution of the reserving treaty or other conveyance. The reservation of rights was not merely for present use, but also for future use[1].

The cases generally hold that the quantity of Indian water rights is to be measured by the amount required for irrigation of all lands located within the reservation which are susceptible of irrigation[2]. Under this test, Indian water rights can be quantified with reasonable accuracy by factoring in the number of irrigable acres on the reservation, the nature of the soil, and the water duty of the various crops which are capable of being grown in the particular climate. One Court has also included as a factor the Indian population trend on the particular reservation[3]; however, this is an isolated case, and probably would not be followed today.

There is some question whether the "irrigation test" has settled the issue of the quantitative extent of Indian reserved rights. It has been asserted that the computation of such rights should not be restricted to an agricultural standard, and that Indian rights also extend to future non-agricultural uses, such as mining or manufacturing. This issue has never been the subject of litigation. It is obvious that any future rulings on this issue favorable to the Indians would drastically increase the quantity of their water rights.

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[1] U.S. v. Ahtanum Irrigation District, Note 1, supra. at page 326.

[2] Arizona v. California, Note 6, supra. at page 601; U.S. v. Ahtanum Irrigation District, Id. at pages 326-327.

[3] In U.S. v. Walker Irrigation District, 104 F.2d 334 (1939), the Court ruled that the area of irrigable land included in the Indian reservation was not necessarily the criterion for measuring the amount of water reserved for the Indians. Instead, the Court based its findings on evidence that the Indian population had shown no increase in the previous 70 years; and that there were not sufficient people to irrigate all the land. This decision seems to ignore the general rule that water rights were to be reserved for the Indians' future use.

To summarize the second issue, irrigation potential is the present measure of Indian reserved rights; however, this method of measurement could be altered by future Court decisions.

3. How Do Indian Water Rights Relate to State Water Allocation Systems.

It is the general rule that the Indian tribes do not derive their water rights from the States[1]. Thus, the traditional appropriation and riparian doctrines do not apply to Indians, at least with regard to acquisition and abandonment of water rights. Indian rights have, however, traditionally been discussed in terms of priority dates, which are a part of general appropriation doctrine (see the foregoing discussion in this memorandum). If elements of the appropriation doctrine still do apply to Indian rights, it is difficult to see how the issue of priority dates is relevant in states which utilize the riparian theory of water rights, since priority dates are not an element of riparian doctrine[2]. To my knowledge, this question has never been discussed in any case involving Indian water rights.

In summary, general rules apply to each of the three basic issues concerning Indian water rights; however, a multitude of unanswered questions still exists with regard to these general rules. The existence of these questions makes it extremely difficult to make any kind of prediction as to the nature and quantity of water rights accruing to Indians in the Northern Great Plains region.

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[1] U.S. v. Ahtanum Irrigation District, Note 1, supra. FPC v. Oregon, 349 U.S. 435.

[2] Of the three states within the Northern Great Plains region, only Montana can be said to have refused to recognize the riparian doctrine. Riparian rights were recognized in the original Dakota Territory, and such rights continue to exist to some extent in both North and South Dakota. See 1 Hutchins, Water Rights Laws In The Nineteen Western States pp. 190-198.

APPENDIX IV

A GENERAL DISCUSSION OF RESERVOIR LIMNOLOGY

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INTRODUCTION

If coal development in the Northern Great Plains proceeds, many coal conversion facilities will be built. The estimated water requirements for these conversion facilities made by the Northern Great Plains Resource Program exceeds the current storage capacity in certain locations of the Northern Great Plains. This will necessitate construction of reservoirs to meet the additional water needs. At the present time there is an insufficient understanding of the effects that the impoundments would have on the water quality of the streams in the Northern Great Plains.

In order to predict the water quality changes resulting from impoundment of a river, a general understanding of the broader science of limnology is required. Reid (1961) defined limnology as: "an area of science concerned with the characteristics of inland waters, the interrelationship between water and basin, and the community of living organisms inhabiting the environment." Water quality describes the chemical and physical regimes within a water body, whereas limnology is concerned with the outside factors regulating water quality as well as the affects of the water quality on the biological productivity.

The biological productivity is the ability of the organisms inhabiting a reservoir to grow and reproduce. Biological productivity can occur in any of organism groups; algae, aquatic insects, or fish. Fig. 1 is a diagramic illustration of the factors which regulate biological productivity of a reservoir.

A literature survey was conducted to learn how each factor illustrated in Fig. 1 affected reservoir water quality and biological productivity. The number and complexity of the regulating factors shown in Fig. 1 precluded a detailed discussion of them within the time frame of the present study. A brief explanation will be presented how each factor contributes to regulating the chemical and physical regimes in a reservoir. The chemical and physical parameters will be related to their effects on the specific components of the biological community; plankton, macroinvertebrates, and fish. A discussion will be made to show the importance of algae and macroinvertebrates to a productive reservoir sport fishery. Finally, some comments will be presented to show the effect of dam discharges on downstream biota. This format should create a basic understanding of the dynamics governing physical, chemical, and biological processes within a reservoir for those unfamiliar with the science of limnology.

References are made to lakes and reservoirs throughout this paper. Similar limnological phenomena may occur in both lakes and reservoirs, however, there are basic differences between the two.

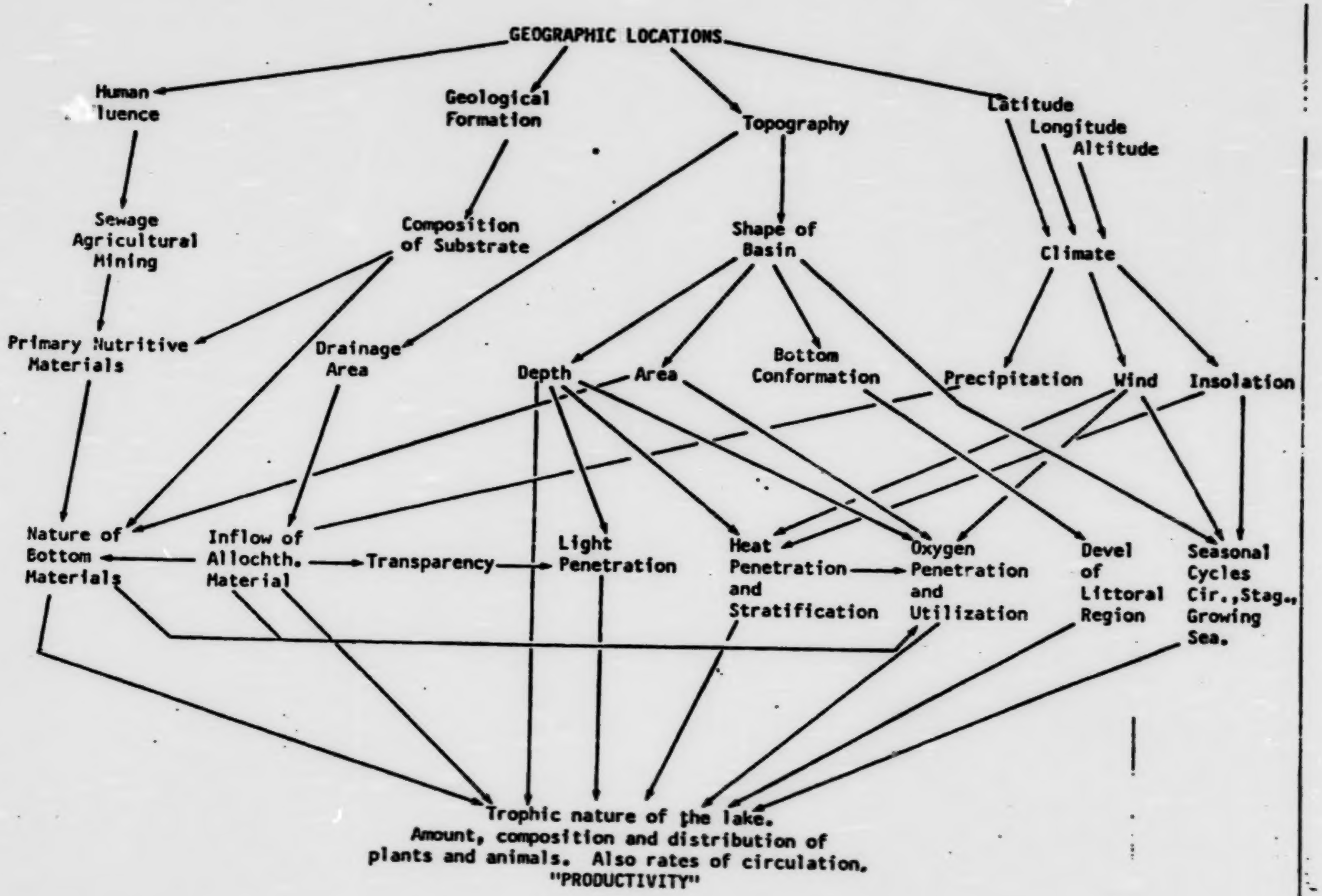
GEOGRAPHIC LOCATIONS
Human Iluence
Geological Formation
Topography
Latitude
Longitude
Altitude
Sewage Agricultural Mining
Composition of Substrate
Shape of Basin
Climate
Primary Nutritive Materials
Drainage Area
Depth
Area
Bottom Conformation
Precipitation
Wind
Insolation
Nature of Bottom Materials
Inflow of Allochth. Material
Transparency
Light Penetration
Heat Penetration and Stratification
Oxygen Penetration and Utilization
Devel of Littoral Region
Seasonal Cycles Cir., Stag., Growing Sea.
Trophic nature of the lake.
Amount, composition and distribution of plants and animals. Also rates of circulation.
"PRODUCTIVITY"

Figure 1. A diagram showing contributions toward a lake productivity from factors inside and outside the water. (After Prescott, 1963 and Rawsou 1940).

Lakes are usually natural bodies of water, whereas reservoirs are man made. The deepest section of a lake is generally located near its geographic center, while a reservoir's deepest water is situated just upstream from the dam. Water that is discharged from a lake originates from the surface water layer, whereas water discharged from a reservoir may arise from any depth depending upon penstock (water intake) locations in the dam profile. This final difference is probably the most important between the two. The subsurface withdrawal of water from reservoirs may cause loss of nutrients from the reservoir, creation of density currents, and downstream water quality problems associated with the chemical nature of the subsurface water itself. These problems are generally not associated with natural lakes.

Predicted water quality for the proposed reservoirs in the Powder River Basin, Wyoming, appearing in the main text of this interim report, were based on correlation of the general limnological cycles presented in this appendum and data relating specifically to the Powder River Basin.

FACTORS REGULATING RESERVOIR WATER QUALITY

Latitude and Altitude

Geographic locations are represented in Fig. 1 as ultimately determining the trophic (food or nutritional) structure of a lake. This is related to climate and its variations between geographic regions. Generally speaking biological productivity of a reservoir or lake is decreased with an increase in altitude or latitude. Bennett (1970) summarized a theory by Thompson (1941) relating fish productivity to latitude (Tab. I).

Table I

Effect of latitude on annual fish yield as estimated from mean monthly temperatures of different localities. (After Bennett, 1970).

Locality	Latitude	Maximum annual yield as percentage of carrying capacity
Vilas County, Wis.	46° N	21
Madison, Wis.	43° N	39
Urbana, Ill.	40° N	50
Cairo, Ill.	37° N	74
Memphis, Tenn.	35° N	86
Jackson, Miss.	32° N	102
New Orleans, La.	30° N	118

The data presented in Tab. I show a decrease in fish productivity with an increase in latitude, but may have been biased by other factors. These include local fishing pressure, catchability of the fish, and undetermined food interrelationships (Bennett, 1970).

Pennak (1945) reported on the regional limnology of northern Colorado lakes (Tab. II). His data indicated a decrease in productivity (organic material - mainly plankton) with increasing altitude. While the average data did indicate the above trend, the variance of the data within each limnological zone made the author hesitant about stating the existance of a definite correlation between productivity and altitude. Pennak did find productivity to be considerably higher in the plains lakes than in the mountain lakes.

The basic consideration underlying the latitude and altitude productivity concept is climate, and the length of growing season.

Table II

Ash content and organic content of 100 lake-water residues from northern Colorado. (After Pennak, 1945).

Limnological Zone	Altitude Meters (feet)	Ash content, mg/l range	mean	Organic content mg/l dry weight range	mean
Alpine	above 3200 (10,464)	9.66 - 49.3	20.35	2.17 - 12.60	5.38
Montane	2500 - 3200 (8200 - 10,464)	5.67 - 95.4	33.57	1.90 - 32.38	11.53
Foothills	1700 - 2500 (5576 - 8200)	23.52 - 261.43	100.31	3.78 - 24.04	12.51
Plains (nonalkali)	below 1700 (5576)	58.20 - 333.60	196.49	4.90 - 60.73	22.79
Plains (alkali)	below 1700 (5576)	475.39 - 11,093.95	1925.36	11.80 - 1210.40	242.19

It is widely recognized that an increase in latitudes and elevation will generally decrease average annual temperatures and length of growing season.

Geological Influences

Hem (1957) reported water chemistry of a river or lake being largely determined by the geological and climatic influences of the river or lake basin. Baranov (1961) found that dissolved mineral content (summation of sodium, potassium, calcium, magnesium, sulfate, and hydrocarbonate ions) of reservoirs in European USSR increased as one progressed in a series of soil and climatic types from the mountains, to the plains. This same trend was established by Pennak (1945) where he found that dissolved mineral content (ash content, Tab. II) increased from the mountains to the plains lakes.

Both Baranov (1961) and Pennak (1945) reported the dissolved mineral content of lakes as being an indication of the resistance or susceptibility of the basins geological formations to chemical weathering. They reported the relatively low dissolved mineral content of the mountain lakes as resulting from resistance of mountain rocks and soils to chemical weathering. The high mineral content reported in the plains lakes (ash content, Tab. II) was due to the leaching of the easily soluble anions such as sulfates and carbonates from the prairie soils. Both authors recognized the existance of two distinct types of prairie lakes, alkali and nonalkali. They differed somewhat on their definition of the two types of prairie lakes. Baronov reported 1000 mg/l dissolved minerals as the upper limits of the nonalkali lakes and Pennak designated the upper limits of the nonalkali lakes to be 500 mg/l total residue*. Both authors reported alkali lakes mineral content as reaching over 10g/l.

While the data presented in Tab. II indicated an increase in productivity with a decrease in altitude, the productivity was probably also a result of the increased mineral content of the lake. The mean productivity (organic content) of the nonalkali prairie lakes (22.79 mg/l) was considerably lower than the alkali prairie lakes (242.19 mg/l).

Nutrients

The preceeding section attributed increased productivity with increased mineral content. The dissolved minerals are the source of nutrients for algal growth in a lake. Elements listed as being essential for algal growth by EPA (1971) are: phosphorus, magnesium, sulfur, calcium, carbon, sodium, potassium, nitrogen, boron, manganese, zinc, cobalt, copper, molybdenum, and iron. While there is not a well defined correlation between the concentration of minerals in a reservoir and its productivity, it can generally be stated that increased mineral content would favor higher productivity.

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* Total residue included ash content plus organic content. The percentage organic content in the total residue of the nonalkali (11.3%) and alkali (10.1%) lakes however, were similar. Therefore the difference between the two types of lakes was mainly due to dissolved minerals. Compare increase in ash content, Tab. II.

The two nutrients that have received increasing attention within the last few decades are phosphates and nitrates. These two nutrients, especially phosphates, are the nutrients most often limiting to algal growth in a lake or reservoir (Hutchinson, 1957). Large amounts of nitrates and phosphates discharged into a lake may greatly stimulate algal growth. This proliferation of algal growth is termed an algal bloom. Intense algal blooms are undesirable in a lake because they may result in decaying windrows of dead algae along the lake shore and fish kills. The fish kills result from the depletion of dissolved oxygen in the water caused by algal respiration, or from toxins released by the algae.

The attention given to phosphates and nitrates has resulted from the practice of discharging domestic sewage effluents into the lakes and streams. Nitrogen and phosphorus are found in high concentrations in sewage plant effluents if the treatment processes do not involve technology specifically designed to remove these two elements.

The National Technical Advisory Committee (1968), in an effort to prevent such algal nuisances, established guidelines to limit nitrogen and phosphorus introduction in the nations waterways. The committee, stating that naturally occurring nitrogen - phosphorus ratios are about 10:1, recommended that any additions of effluents to lakes or reservoirs not radically alter this naturally occurring ratio. The committee also contended the introduction of phosphorus should not be increased to 50 ug/l where streams enter lakes or reservoirs.

While it is recognized that nitrogen and phosphorus are often the limiting factors to algal growth in a lake, natural conditions do exist where algae are not limited by these two nutrients, but still fail to become nuisance organisms. Wright and Soltero (1973) classed Bighorn Lake, Wyoming, as being only a moderately productive reservoir but the alga growth was not limited by nutrient supply. Varley (1967) reported a bloom of the bluegreen alga, Aphanizomenon flos-aquae, in Flaming Gorge Reservoir, Wyoming, in 1965, but not the following year. Nutrients (nitrogen and phosphorus) were not limiting either year.

Natural conditions also occur where levels of nitrogen and phosphorus in a lake are very low but algal growth is stimulated by very small increases in the nutrient level. Growth of Selanastrum capricornutum inoculated into water from Dillon Reservoir, Colorado, was stimulated by as little as 5 ug/l increase in phosphorus (Swallow and Eddy, unpublished). Ambient concentrations of phosphorus in the Dillon Reservoir were 5 ug/l or less. The 5 ug/l level is also considerably less than the National Technical Advisory Committee 50 ug/l guideline for limiting algal growth.

As previously mentioned, algal blooms have occurred with adequate nutrient supply. In other situations, however, nutrients were not limiting but algal blooms failed to develop. Likewise very minute additions of nutrients to a reservoir water have been reported to increase algal growth. Since all of the above conditions can exist in nature and potential sources of sewage effluents to the proposed study area (Powder River Basin) are limited, no attempt will be made to establish specific nutrient requirements for algal growth in the proposed reservoirs. Subsequent discussion shows that algal growth is dependent upon many interrelated parameters.

One source of nutrients reported in the literature, in addition to geological and domestic sources, is unique to a newly formed reservoir. This is the release of nutrients from the decaying plant material following inundation of the reservoir basin. Numerous authors reported increased productivity of a river following its impoundment due to sudden increase in nutrient availability, (Aggus, 1971; Ellis, 1937; and Ioffe, 1961). Thomas (1969) also reported leaching of nutrients from the inundated soils of Wilson Reservoir, Kansas.

Allochthonous material (decaying organic material carried into a reservoir by surface runoff or tributary flow) was found to be another source of nutrients for an aquatic habitat. Minshall (1967) found that the primary source of nutrient supply in a small stream in Kentucky was allochthonous material in the form of leaf materials. The significance of this source of nutrients to a reservoir, however, will probably be very low unless the reservoir is small and located in a heavily forested area.

Temperature

Once the nutrients have entered a reservoir, their utilization in biological productivity is largely dependent upon the physical regimes existing within the water. Reid (1961) listed temperature as the regulating force in many physical, chemical, and biological reactions. Carlander (1969) reported temperature as influencing the onset of feeding, and spawning activities of fish. Hutchinson (1957) presented data showing the temperature dependence of some algal species. These authors indicated that temperature was probably one of the most important physical regulating factors in an aquatic environment.

The flow diagram in Fig. 1 indicates that temperature in a reservoir is controlled by numerous outside factors: insulation, wind, and reservoir mophometery (length, width, and depth ratios). These contributing factors have also been listed by Symons, Weibel, and Robeck,(1969). Other factors contributing in some degree to temperature regulation in a reservoir are precipitation, ice cover, and density currents. Water temperature-density relationships also contribute significantly in regulating temperatures in a reservoir.

Water has the unique characteristic of being densest at approximately 4 C (Fig. 2). Water at temperatures either higher or lower than 4 C will be less dense than the same water at 4 C. It is this characteristic that allows ice to float on a lake surface, or for cold water to be located near the bottom of a lake during the summer while the warmer water lies near the surface. This latter process occurring during the summer is termed summer stratification. The development of this phenomenon and its annual cycle significantly affects all aquatic organisms within a reservoir.

A typical northern temperate lake is ice covered during the winter. An inverse temperature curve may develop by virtue of the temperature density relationship where it is colder just under the ice and warmer near the bottom of the lake (Fig. 3a). Although not large, this temperature gradient remains stable because the ice cover prohibits wind mixing of the water. Following the spring thaw and gradual warming, the water temperature is homogenous throughout the entire lake (Fig. 3b). This uniform temperature and density coupled with the spring wind action help to completely circulate the lake water. The magnitude of this circulation is sufficiently great to induce circulation of some to the bottom sediments. This process is termed vernal or spring turnover. It is important as a renewal of algal nutrients that have accumulated in the bottom sediments during the winter period.

Following spring turnover the surface water of the lake is warmed by incoming solar radiation. Reid (1961) reported that over 50% of the absorbed solar radiation is lost in the first two meters of water column. Because of this, the subsurface waters of the lake warm relatively slowly in comparison to those near the surface. Warming of the subsurface water is accomplished mainly by the convection currents established by surface wind action. A density gradient that becomes more resistant to further mixing by the wind is slowly established in the water because of the differential rate of warming. When this temperature-density gradient has reached sufficient magnitude any further circulation of the bottom and surface waters is prevented. This situation is called summer stratification (Fig. 4a).

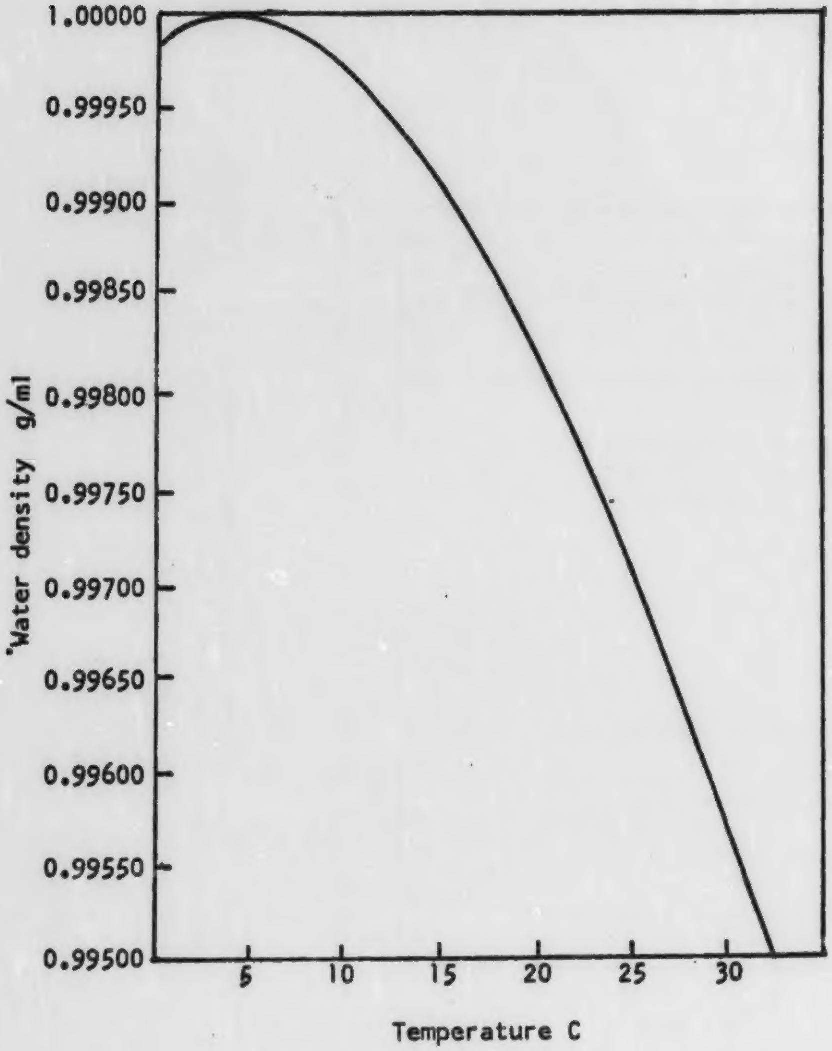


Fig. 2. Water temperature-density relationships. (After Symons, Weibel, and Robeck, 1969)

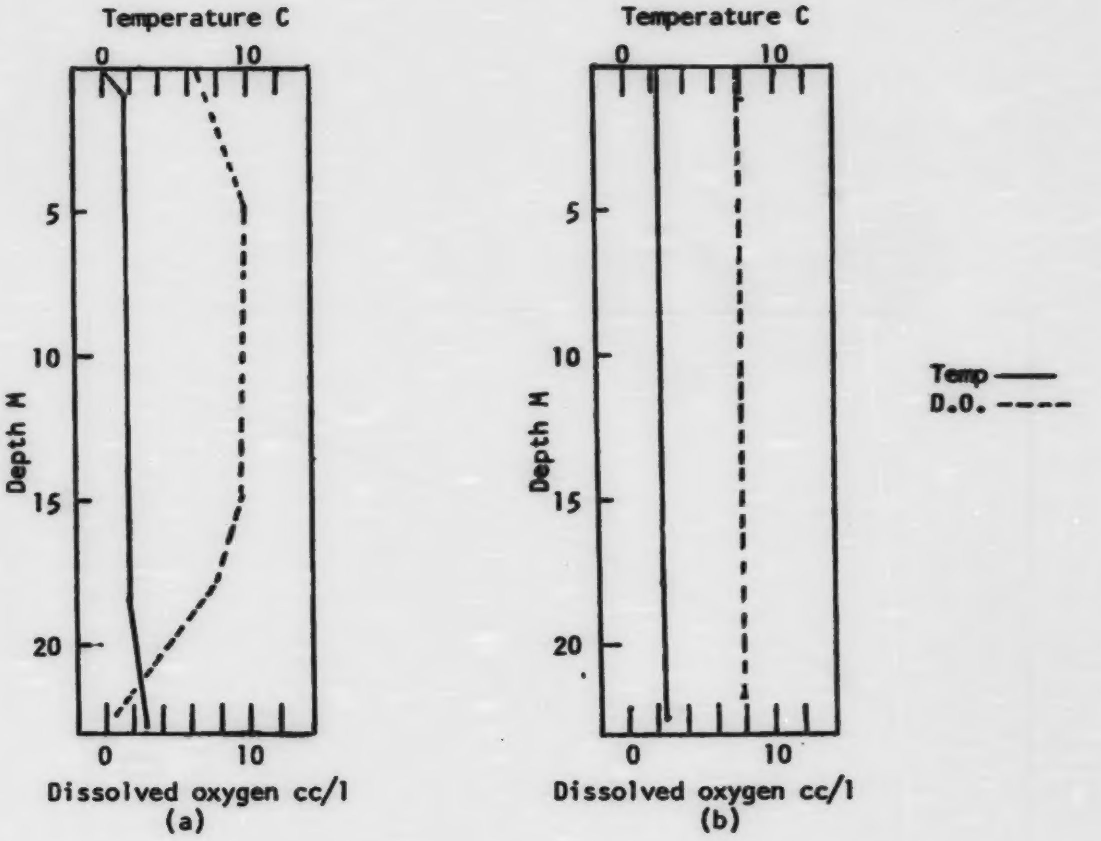


Fig. 3. Temperature and dissolved oxygen of Lake Mendota, Wisconsin during March 8, 1906 (a) and April 9, 1906 (b). (After Birge and Juday, 1911).

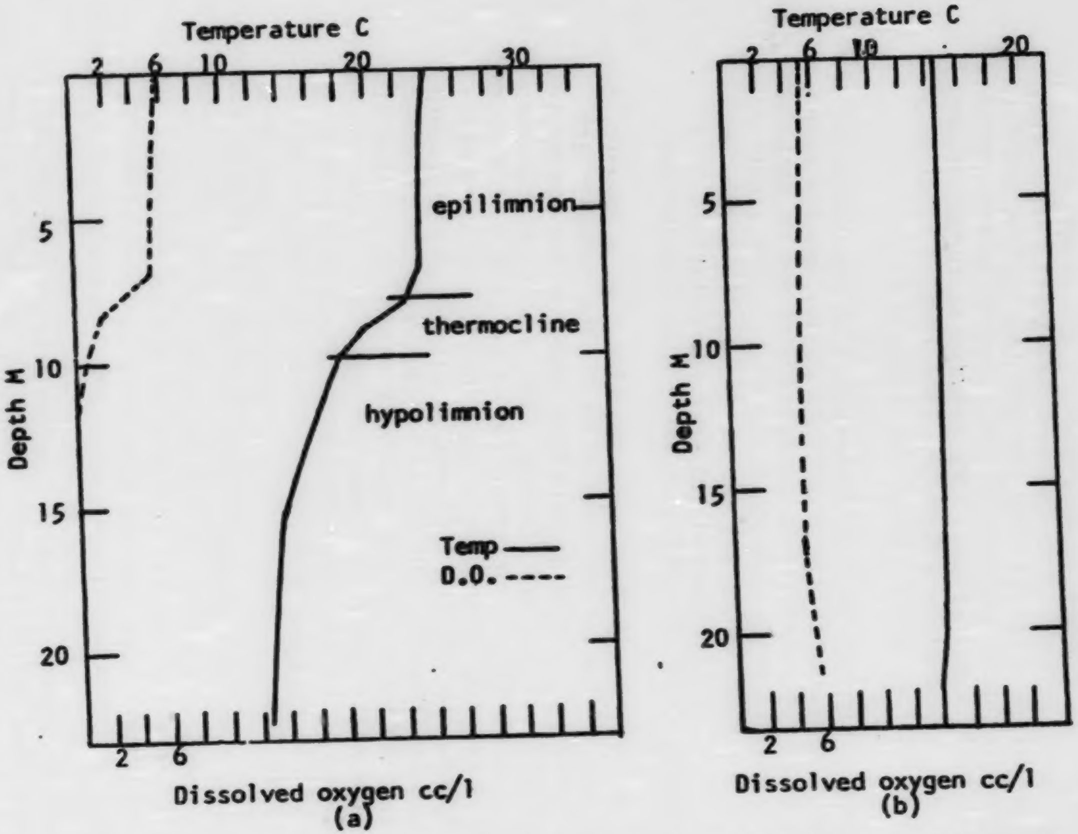
Terms have been established to describe the different zones of the lake during this period (Fig. 4a). The epilimnion is the upper layer of water, and is usually warm and relatively homothermal during the summer. The zone of rapidly decreasing temperature lying beneath the epilimnion and above the colder bottom water is termed the thermocline. The hypolimnion is that region of cold water lying below the thermocline and reaching to the bottom of the lake.

Surface water temperature is decreased in the autumn with decreasing air temperatures. Once the surface waters have cooled to the same temperature or below those of the thermocline and hypolimnion the water is again completely circulated by inverse density gradients and surface wind action. This process is termed autumnal or fall turnover. Temperature within the lake remains relatively constant until ice formation in the winter (Fig. 4b).

Other factors reported to have contributed to regulation of the thermal regime in a reservoir are precipitation and density currents. June (1968) reported temperatures in isolated portions of Oahe Reservoir, South Dakota, being decreased between 4 and 6 C. within a half hour. This sudden drop in temperature was caused by locally severe hail storms. Wunderlich (1971) reported temperature variations in a thermally stratified reservoir being caused by density currents.

A density current was defined by Weibe (1941) as a "gravity flow of a fluid within a medium of the same phase." The currents are developed as a result of differing densities between the reservoir water and those of its tributary streams. The density differences can be caused by temperature, concentration of solutes, and turbidity. Wunderlich (1971) reported three basic types of density currents exist depending upon the density differences between the tributary and reservoir waters (Fig. 5). Overflow is caused by inflow water density being less than that of the reservoir water. Underflow is caused when inflow water density is greater than that in the reservoir. Interflow is caused by inflow water that is at first denser than the reservoir water, then eventually reaches a density layer in the reservoir less than itself. Weibe (1941) reported that long, deep, and narrow reservoir conformation favors development of density currents. Wright and Soltero (1973) reported subsurface withdrawal contributed to formation of density currents in Bighorn Lake, Wyoming. While Wunderlich (1971) reported density currents affecting reservoir temperature, they appear more important as causing fluctuations in dissolved oxygen, and nutrient dispersal in the reservoir (weibe, 1941).

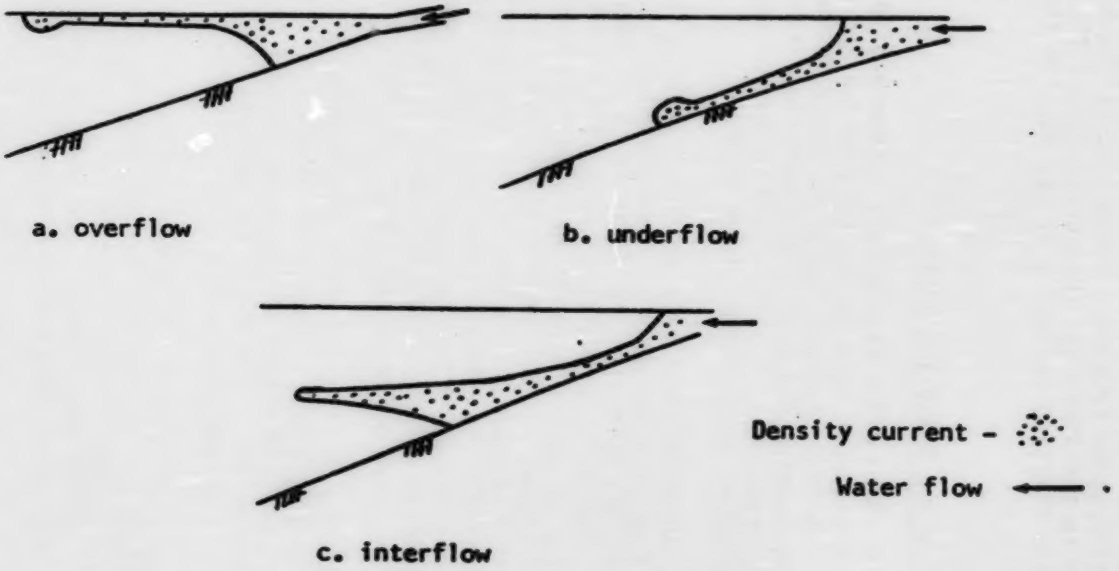
The preceeding discussion showed how temperature variations may result in a reservoir. Surface water warming is accomplished from solar radiation. Heat exchange between the surface and subsurface waters is accomplished almost entirely by wind circulation. The efficiency of the wind in successfully transferring the heat within



(a)

(b)

Fig. 4. Temperature and dissolved oxygen of Lake Mendota, Wisconsin during August 1, 1906 (a) and October 11, 1906 (b). (After Birge and Juday, 1911)


Density current -
Water flow

a. overflow

b. underflow

c. interflow

Fig. 5. Three types of density currents that may occur in reservoirs. (After Wunderlich, 1971)

the reservoir is dependent upon the water density and depth. A shallow reservoir with a large surface area exposed to the wind will have a homogenous water temperature throughout most of the year. A reservoir that is narrow and deep, will probably have summer stratification develop. Thermal stratification is of significance to the limnology (productivity) of the reservoir because of the limiting influence it may have on the reservoir organisms.

Stratification and Dissolved Gases

Once the thermocline has formed, exchange of dissolved and particulate substances between the hypolimnion and epilimnion is prohibited. Various chemical reactions occur in the hypolimnion causing it to develop chemical characteristics incompatible to most aquatic organisms. For this reason thermal stratification is sometimes referred to as summer stagnation.

During summer stagnation plankton organisms that have settled to the hypolimnion after dying are subjected to bacterial decomposition. In a newly formed reservoir the decay of basin vegetation results from similar bacterial processes. This bacterial action results in the liberation of carbon dioxide and a depletion in dissolved oxygen in the hypolimnion. If the reservoir is deep enough to permit stratification, this decomposition process is sufficient to deplete the hypolimnion of all dissolved oxygen (Fig. 4a). Reduced dissolved oxygen concentrations caused by decay of basin vegetation in newly formed reservoirs were reported by Thomas (1970) and Lucas (1971) with dissolved oxygen levels reported less than 1 mg/l.

The epilimnion of a reservoir experiences little oxygen depletion under normal conditions. Oxygen is supplied to the epilimnion from contact with the atmosphere and algal photosynthetic activities (see equation p. 30). The dissolved oxygen is evenly disbursed in the epilimnion by the wind action.

Intense algal blooms can drastically alter oxygen conditions of the epilimnion. During the day the photosynthetic activity of the algae may actually supersaturate the epilimnion with oxygen. Night time respiration, however, can lead to severe oxygen depletion. The oxygen depletion, in turn, can cause fish kills.

Ammonia and hydrogen sulfide are produced by anaerobic decomposition of nitrate and sulfate compounds in the hypolimnion. McKee and Wolf (1963) reported these compounds toxic to aquatic organisms in their unionized forms, the relative ratio of the ionized to unionized forms being dependent upon pH of the water. The production of hydrogen sulfide at toxic levels (786 mg/l) has been reported under extreme hypolimnetic conditions (Symons, Wiebel, and Robeck, 1969). References attributing fish kills in reservoirs to the toxic effects of these two compounds, however, have not been found.

Ammonia production in the hypolimnion is significant because it represents a potential reservoir for production of nitrate during the fall turnover. The renewal of nitrates and other nutrients from hypolimnetic waters, however, may be reduced by reservoir operational procedures.

Stratification and Nutrients

Nitrates, phosphates, and the various other nutrients are liberated upon the decay of plants and animals in the hypolimnion. The nutrients are trapped in this layer until fall turnover. Subsurface withdrawal from reservoirs can significantly reduce the amount of these nutrients in the hypolimnion. Wright and Soltero (1973) reported a loss of 75% of the total nitrogen (mainly as ammonia) and 14% of the total phosphorus that entered Big Horn Lake, Wyoming. This loss was caused by water withdrawal from hypolimnetic waters. Weibe (1941) reported the possible loss of nutrients from a reservoir by entrapment in density currents passing through the reservoir. In both of these instances, the nutrients were not available for algal growth, as most algal growth is limited to the epilimnion due to sunlight availability.

Light

Photosynthesis is a photochemical process performed by algae and aquatic plants. Plant biomass (living weight) is increased by this process by the conversion of inorganic nutrients into plant tissue using light as an energy source. Since light may be a limiting factor in this process, it follows that all photosynthesis will be limited to that part of a reservoir where there is sufficient light penetration.

The flow diagram in Fig. 1 shows that light penetration in a lake is dependent upon the water transparency and depth. Other factors limiting light penetration in the water column may include water color and the density of the plant (algae) community itself, (Reid, 1961). The region where sufficient light penetrates to permit photosynthesis is termed the euphotic zone.

Most aquatic plant forms are limited in their distribution to the euphotic zone, which enables them to utilize the available sunlight for photosynthesis. Planktonic (floating) algae are able to remain suspended in the euphotic zone of a reservoir by virtue of their bouyancy. There are other forms of plant life that exist in a reservoir that are anchored to the bottom, and therefore restricted to those shallow areas of the lake where light penetration is sufficient to permit growth. The second group of plants include periphyton (attached) algae and aquatic macrophytes (vascular aquatic plants).

Littoral Zone

The shallow water zone where the periphyton and macrophytes are capable of growing is termed the littoral zone of a reservoir. The amount of littoral area in a reservoir is determined by basin conformation. A reservoir with a narrow deep basin will have a small amount of littoral area compared to a reservoir formed over a wide shallow flood plain. The littoral zone is important to fisheries also because it serves as spawning grounds for important sport fish.

BIOLOGICAL PRODUCTIVITY

The preceeding discussion elaborated on the various physical and chemical parameters within a aquatic environment which regulate the biological productivity. Reference was made to the productivity of algae and fish. What is the significance of these two types of productivity, and how are they related?

All living animals in a reservoir are ultimately dependent upon the photosynthetic process (primary production) performed by the algal community as a food source. The food produced by the algae is made available to the fish by its transfer through the various food chains. A simple example of a food chain is algae being eaten by aquatic insects, which in turn are consumed by fish. This simple scheme can become complicated however, because it may represent only one food pathway from the algae to the fish. Fig. 6 is an example food web of a lake containing two major predators, white bass, and rainbow trout. Several food sources are available to the sport fish. The reliance of the trout or bass on each specific food source will vary with age of the fish, time of year, and availability of the food. Add to this fact that periphyton, aquatic macrophytes, and allochthonous material are not represented in the diagram, and the reader can appreciate the complexity of an aquatic food web that may exist in a reservoir.

The length of the various food chains determines the amount of biomass produced by the algae that finally reaches the fish. The data presented in Tab. III illustrate the efficiency of energy transfer between each trophic (food) level in three aquatic environments. As each trophic level utilizes the preceeding one as a food source, a large portion of the energy is lost in the biomass conversion. This loss of energy is due mainly to heat loss by respiration.

Greater fish yield could be realized from a reservoir if fish were harvested at the secondary consumer level (forage fish) rather than the tertiary consumer (sport fish) level. The energy loss between these two trophic levels would not then be realized. The difference in fish yield rates at these two trophic levels was recorded by Odum (1959) using data from (Hickling, 1948; and Viosca, 1935). The yield of fish from a carp pond ranged from 100 - 348 lbs/acre/yr (11.2 - 39.0g/m^2/yr), and the yield from a sport fish pond ranged between 40 - 150 lb/acre/yr (4.5 - 16.8g/m^2/yr). The American trend however, has placed more emphasis on a sport fishery because of the aesthetic enjoyment and the amount of economic input from sportsmen to the local reservoir area.

The discussion concerning food and energy relationships illustrated how sport fish production is controlled by the productivity of the lower members of the food chain existing in a reservoir. Numerous researchers have attempted to establish a correlation between the primary productivity and fish yield from reservoirs. Rupp and DeRoche (1965) failed to establish a correlation between primary productivity and fish yield in three Maine lakes. Nicola and Borgensen (1970) failed in their attempts to establish a correlation between primary

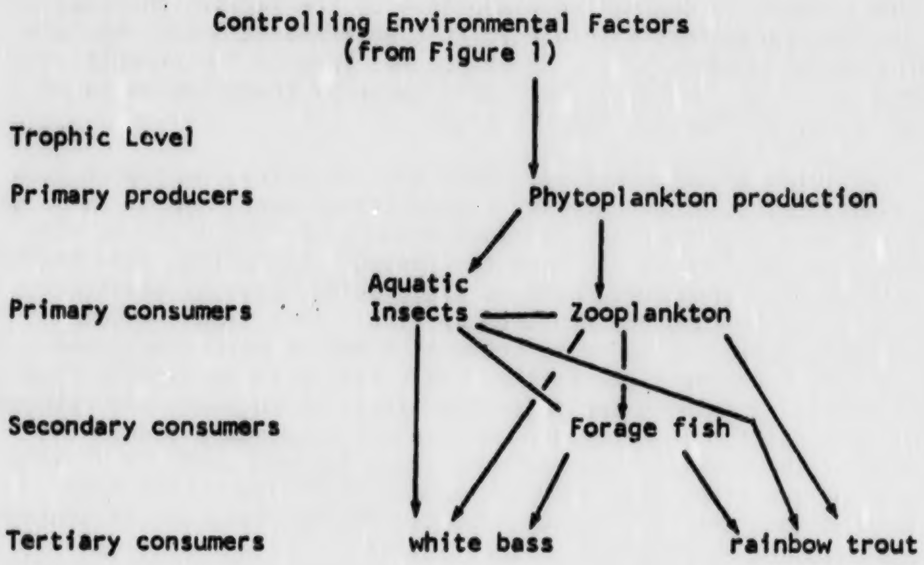

Controlling Environmental Factors
(from Figure 1)
Trophic Level
Primary producers
Phytoplankton production
Primary consumers
Aquatic Insects
Zooplankton
Secondary consumers
Forage fish
Tertiary consumers
white bass
rainbow trout

Figure 6. A diagramic illustration of the possible food web that may exist in a reservoir or lake with two major sport fish.

Table III

Efficiency of energy transfer at various trophic levels in three aquatic ecosystems. (After Odum, 1957, tabular data appearing in the table was obtained from research by: Lindeman, 1941 and 1942, Juday, 1940, and Odum, 1957).

Trophic level	Trophic level energy efficiency (%)		
	Cedar Bog Lake Minnesota	Lake Mendota Wisconsin	Silver Springs Florida
Photosynthetic Plants (producers)	0.10	0.40	1.2
Herbivores (primary consumers)	13.3	8.7	16.0
Small carnivores (secondary consumers)	22.3	5.5	11.0
Large carnivores (tertiary consumers)	not present	13.0	6.0

productivity, zooplankton standing crop, and fish yield in three California reservoirs. Nicola and Borgensen (1970) listed two major problems that must be considered in trying to correlate primary productivity and fish yield. They are the inability to define and quantitate the varying number of trophic pathways between the phytoplankton and fish, and the direction and efficiency of energy transfer within and between these trophic levels.

Some authors have gone a step farther, and tried to correlate reservoir nutrient content, area, and depth to fish yield (Bennett, 1970). This correlation would appear even more difficult to establish than primary productivity and fish yield because of the other environmental factors controlling algal production. Bennett stated that "such studies are useful to estimate production on a broad basis, but can scarcely be applied to individual lakes."

Even though the complexity of the food web has made correlation of fish productivity and lower food web productivity difficult, it is generally recognized that the growth rates and productivity of fish are dependent upon the productivity of the lower trophic levels of the food web.

PRIMARY PRODUCERS

Periphyton and Macrophytes

Periphyton was previously described as being attached algae. This algal community is composed of: green algae (Chlorophyta), bluegreen algae (Cyanophyta), yellow green algae to include the diatoms (Chrysophyta), red algae (Rhodophyta), and yellow brown algae (Pyrrhophyta). Objects on the reservoir bottom or the stems and leaves of aquatic macrophytes are used as substrates by the periphyton.

The aquatic macrophytes are the higher plants within the reservoir. This community while being composed of numerous plant species, may be subdivided into three zones based on growth habits, emergent, floating leafed, and submergent. The emergent plants grow in the water but have most of their vegetative parts above the water line. They are usually located near the shoreline, and are represented by types such as cattail (*Typha* sp.) and bulrush (*Scirpus* sp.). The floating leafed zone is typified by plants such as the water lily (*Nymphaea* sp.) and water shield (*Brasenia* sp.). The submergent vegetation extends out into the reservoir to the point where light penetration becomes limiting to their growth. This point marks the end of the littoral zone. Plants inhabiting the submergent zone include the pondweed (*Potomogeton* sp.) and hornwort (*Ceratophyllum* sp.).

The macrophyte-periphyton association accounts for the high productivity of the macrophyte zone. Macrophytes offer a readily available food source for primary consumers, but are not eaten to any great extent by these organisms (Odum, 1959). The macrophytes, however, do furnish substrate for the periphyton attachment which are valuable food items for the primary consumers. At the same time macrophytes offer shelter for the organisms living in this zone.

As previously mentioned the macrophytes are limited by depth of light penetration. Boyd (1971) also listed numerous other factors that limit endemic plant species from becoming established in a reservoir: water depth, current, wave action, temperature, transparency, substrate characteristics, water chemistry, and competitive interaction with phytoplankton and other macrophytes. Water level fluctuation seemed the single most important factor regulating macrophyte growth. For this reason, water level fluctuation is used as a reservoir management tool to prevent nuisance growths of macrophytes in reservoirs in some parts of the country (Boyd, 1971).

Phytoplankton

The phytoplankton is composed of the same algal divisions that comprize the periphyton. The phytoplankton can be further categorized on the basis of size. Nannoplankton are those algae that pass through a No. 25 silk bolting cloth net, openings usually ranging between 0.03mm and 0.04mm, while net plankton are those organisms that are retained in the No. 25 net.

The net plankton are the most often reported in algal counts as nannoplankton, by virtue of their small size, cannot be distinguished under the normal magnification (250X) used for these counts. Even though nannoplankton are not reported in normal algal counts they may contribute significantly to total phytoplankton volume and biomass.

Benson and Cowell (1968) reported nannoplankton as comprizing 84% of the phytoplankton volume in three Missouri River reservoirs. Birge and Juday (1922) found in their study of Wisconsin lakes that nannoplankton amounted to 82%, 74%, and 66% of the total phytoplankton volume in Wisconsin lakes of Mendota, Monona, and Waubua, respectively. Findenegg (1967) reported that the nannoplankton have higher assimilation rates than net plankton because of their large surface area in relation to their biomass. These facts illustrate the importance of these minute organisms in the algal productivity of a reservoir.

Previous mention has been made of the photosynthetic activity of algae, and its function in food production. Photosynthesis is also referred to as primary production. Primary production of a phytoplankton community is usually reported in the literature as amount of carbon assimilated or amount of oxygen produced by the algae over given area over a given time. Both reporting procedures can be seen to be valid in terms of the general equation for photosynthesis:

$$\text{Light} + 6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Wright and Soltero (1973) cited Rhode (1958) as arbitrarily assigning a production rate of 0.3 g O_2/m^2/day as the dividing point between unproductive (oligogrophic) and productive (eutrophic) lakes. The range of primary production in productive waters was reported by these authors to be from 1.3 to 8.0 g O_2/m^2/day. Wright and Soltero reported Bighorn Lake as being moderately productive with mean daily net primary production of 1.36 g O_2/m^2/day, 1.46 g O_2/m^2/day and 3.78 g O_2/m^2/day for years 1968, 1969, and 1970 respectively. This illustrated that primary production is not a constant process, and may change from year to year. The authors data also showed drastic fluction in primary production rates throughout different times of the year.

Variations in primary production are caused by: 1) interdependent physical factors, 2) chemical factors - nutrients, and 3) biological interaction of the organisms within the reservoir (Findenegg, 1969; Hutchinson, 1967). The first two factors of course are composed of the parameters illustrated in Fig. 1. The changes in the primary production rates in reservoirs are caused by the variations in its phytoplankton populations. In a typical northern temperate lake the plankton population will vary in magnitude and kinds of organisms with the time of year. The normal succession of phytoplankton in these lakes follows the general sequence of diatoms in the spring, green and bluegreen algae in the summer, and diatoms again in the fall and winter (Wright and Soltero, 1973; Funk and Gaufin, 1971; Varley, 1967).

Fluctuations occurring in the phytoplankton of Lake Mendota, Wisconsin were recognized by Birge and Juday (1922) as early as the first part of this century (Fig. 7). The major population peaks in Fig. 7 were caused by generally one division or in some cases one species of algae. The prominent increases in plankton populations in April, 1916 and May, 1917 were caused by intense blooms of the diatom, Stephanodiscus astraea. The population pulse noted in December, 1916, was attributed primarily to a combination of the diatoms, Asterionella sp., Fragilaria sp., and Stephanodiscus sp. The population surges appearing in May and July, 1916 were predominately the yellow green alga, Chlorochromonas sp., and the bluegreen alga, Aphanocapsa sp. The bluegreen genera Coelosphaerium sp. also contributed significantly to the July pulse.

While the green algae were not reported to have played a major role in seasonal succession in Lake Mendota, the reader can appreciate the fluctuations that do occur in a naturally occurring phytoplankton population.

Numerous authors have noted these fluctuations in seasonal abundance of different species of phytoplankton and have attempted to correlate these periods of abundance to the regulating environmental factors listed above. Wright and Soltero (1973) found that zooplankton predation was a possible reason for the decline of the phytoplankton population in parts of Bighorn Lake, Wyoming. They also found that blooms of the bluegreen alga, Aphanizomenon flos-aquate, limited light penetration and seemingly reduced diatom growth. Taylor (1971) found that nutrients and turbidity limited total algal population and primary production in six TVA reservoirs. Varley (1967) found photoperiod, temperature, visibility, reservoir level, and wind to be regulating factors in abundance of different species of phytoplankton in Flaming Gorge Reservoir, Wyoming. Thomas (1970) noted that a nitrogen phosphorus ratio of less than 7:1 favored development of bluegreen algae in Wilson Reservoir, Kansas. This may have been due to the ability of bluegreen

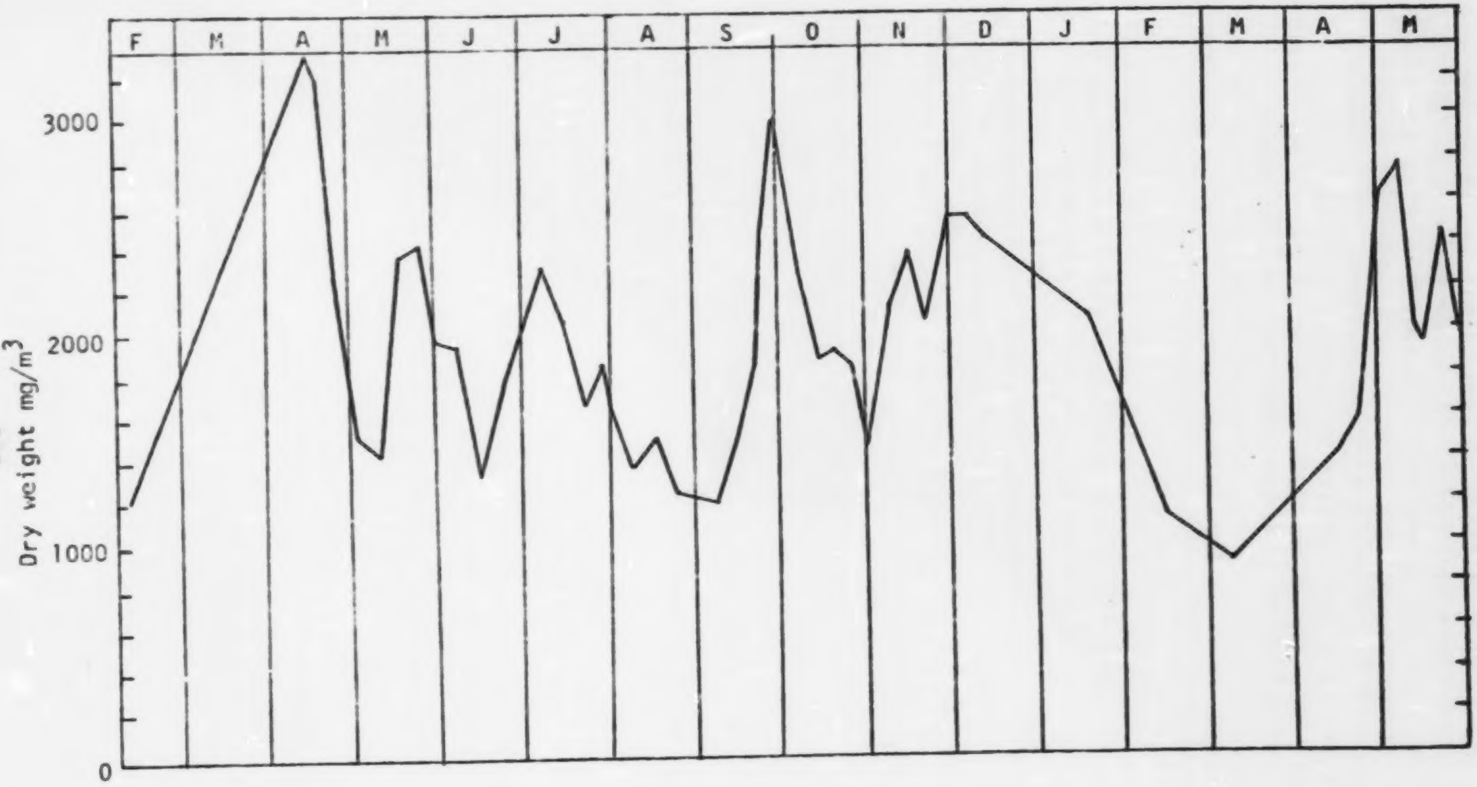


Fig. 7. Amount of dry organic matter (mg/m^3) in the total plankton of Lake Mendota, Wisconsin from 1916 to 1917. (After Birge and Juday, 1922).

algae to fix nitrogen (convert elemental nitrogen into usable nitrate nitrogen). Funk and Gaufin (1971) found phytoplankton populations being regulated by temperature, light penetration, and addition or dilution of nutrients caused by runoff into Lake Viva Naughton, Wyoming. Hutchinson (1967) reported the abundance of diatoms in northern temperate lakes in the spring to be due to increased nutrients from turnover and their ability to grow at lower spring water temperatures.

As illustrated in the preceeding discussion, phytoplankton fluctuations in lakes are caused by many interdependent factors. Lakes can be classed as productive or unproductive using the primary productivity concept. Primary productivity measurements, however, should be conducted throughout as much as the year as possible, because the variations in phytoplankton populations may cause erroneous estimates of the overall productivity of the reservoir.

PRIMARY CONSUMERS

Zooplankton

Zooplankton are the animal components of the plankton community. Zooplankton are composed of numerous members of the animal kingdom chiefly: protozoans, rotifers (microscopic, wormlike to spherical organisms which bear a crown of cilia near the anterior end), and microcrustaceans (a class of Arthropods, segmented legged animals, which have a hard exoskeleton, the chief planktonic representative being copepods and cladocera).

The zooplankton community's primary food source is the phytoplankton. Zooplankton are very important in the reservoir food chain because they are the primary source of food for reservoir forage fish, shad in particular. They may also serve as food for sport fish to some extent. Kokanee salmon have been reported to rely mainly on zooplankton as a food source (Chamberlain, 1972; Nicola and Borgeson, 1970). Rainbow trout were reported to utilize zooplankton as a food source in Flaming Gorge Reservoir, Wyoming until they reached a length of 300 mm (11.8 inches) (Varley, Rogenthal, and Wiley, 1971). White bass have been reported to use the zooplankton to some extent in Lewis and Clark Lake (Ruelle, 1971).

Zooplankton populations have been reported to undergo seasonal pulses similar to phytoplankton (Pennak, 1949; Hutchinson, 1957). Some researchers have attempted to correlate zooplankton abundance to phytoplankton standing crop. No significant correlation, however, could be established between phytoplankton blooms and a succeeding pulse in zooplankton standing crop (Reid, 1961). While zooplankton populations were controlled by food (phytoplankton) abundance, other complicating factors like fish predation, temperature, and interspecific zooplankton competition obscured a clear phytoplankton - zooplankton correlation.

Benthos

Periphyton was previously described as the attached algae. Some authors have expanded periphyton to include all organisms (plants and animals) that are attached or crawl on the reservoir substrate. The term applied to the above benthic (bottom dwelling) community is aufwuchs.

The attached animal components of the aufwuchs are protozoans, rotifers, and bryozoans (small, tufted, gelatinous-like, freshwater organisms ranging up to a few mm in height). Animals that may be found crawling about in this benthic community include: free living protozoans, round worms, rotifers, annelid (segmented) worms, micro-crustaceans, and aquatic insects. These organisms are associated with the littoral zone of a reservoir, and can be very abundant if an aquatic macrophyte community has developed in this zone.

The increased production of a littoral zone with macrophytes as opposed to one devoid of macrophytes was reported by (O'Connell and Campbell, 1953). The year following impoundment of Clearwater Lake, Missouri, very dense beds of the pondweed, Potomogeton pusillus, developed in the reservoir from depths of one to eight feet. Sampling revealed this zone to be "unusually productive" in the macroinvertebrates with 23 different kinds being found. The presence of macrophytes unfortunately precluded quantifying the biomass of this benthic community. The majority of the macroinvertebrates were the mayfly families Baetidae and Ephemeridae, and the midges Chironomidae and Ceratopogonidae. Pennak (1953) listed these organisms feeding habits to be primarily periphyton grazers. Presumably these organisms were feeding on the periphyton attached to the pondweed. The following year the water level rose 30 feet and eliminated the beds of pondweed. Sampling this year revealed a total of only 13 different kinds of invertebrates. This example illustrated the benefit of development of macrophyte growth in the littoral zone to production of the lake.

When a river is impounded there is a drastic change in the environment for the river dwelling organisms. The basic change in benthic fauna that occurs is the loss of the rheophilic (current-liking) forms such as stoneflies and caddis flies. These are replaced by limnetic (lake) forms such as midges, phantom midges and annelid worms.

Isom (1971) listed the following factors contributing to the decline of river benthic organisms in a reservoir: siltation, rheotactile deprivation (current loss), water level fluctuation, increased hydrostatic pressure, and hypolimnetic dissolved oxygen deprivation. Generally a river environment has a more diverse benthic community than a reservoir. O'Connell and Campbell (1953) reported 33 different kinds of invertebrates inhabiting Black River before impoundment, but only 20 kinds following impoundment. Lucas (1971) found only three kinds of invertebrates in two locations in Stockton Reservoir, Missouri following impoundment, and Thomas (1969) reported 31 different kinds from the same locations on the Sac River before impoundment.

The decrease in number of forms between a river and reservoir environment is accompanied with a concurrent increase in organism biomass. Cowell and Hudson (1968) reported the standing crop of macroinvertebrates in the Missouri River to average one Kg/hectare, however, values reaching as high as 70 Kg/h have been reported from the reservoirs of the Missouri system. O'Connell and Campbell (1953) reported the number of kinds of benthic forms dropping after the impoundment of the Black River, but the standing crop increased from $788/m^2$ before impoundment to $1023/m^2$ after impoundment. Ioffe (1961) reported increased production of bottom fauna of the Dneiper River, USSR from 21.7 g/m^2 before impoundment to 168.08 g/m^2 after impoundment.

Cowell and Hudson (1968) found that turnover rate of the benthic community may be as important as a large instantaneous standing crop. They found an average biomass ratio of mayflies to midges of nine:one in Lewis and Clark Lake, South Dakota. Midges by virtue of their high turnover rate (production of several generations in a season) however, nearly equalled the biomass of the mayflies lost from the reservoir on an annual basis.

Data conflicting with the increased benthic production have been reported from other reservoirs. Thomas (1969) and Lucas (1971) reported a decline in numbers and kinds of benthic fauna in their pre-and post-impoundment investigations of Stockton Reservoir, Missouri. They found bottom fauna of the Sac River numbering $262/ft^2$ before impoundment and only eight per square foot following impoundment. Other publications by these authors reported a similiar trend in the impoundment of Chariton River, Iowa (Lucas and Thomas, 1970; Lucas, 1971). In these investigations the authors found 20 kinds of bottom fauna numbering $331/ft^2$ in the Chariton River before impoundment, but only five kinds numbering three per square foot following impoundment. The above losses in productivity in the reservoir environment may have been due principally to sampling locations. The post-impoundment samples were collected from the hypolimnion, and therefore bottom fauna would logically be limited by adverse hypolimnetic conditions.

The affect of the hypolimnion on benthic fauna production was reported by (Agguss, 1971). He found bottom fauna to be concentrated in Beaver Reservoir, Missouri, near the three meter depth. He also reported finding few bottom organisms below nine meter. The thermocline during these studies was approximately six meters, and Agguss postulated severe hypolimnion oxygen depletion as limiting the bottom fauna in this area. Cowell and Hudson (1968) found the mayfly (Hexagenia sp.) was limited in Lewis and Clark Lake to depths less than 10 meters by low dissolved oxygen concentrations. O'Connell and Campbell (1953) also reported decreased numbers of benthic fauna in Clearwater Lake, Missouri, at depths greater than 35 feet.

Shallow depths were also reported to be limiting to littoral macroinvertebrates. Cowell and Hudson (1968) reported mayfly and midge distribution in Lewis and Clark Lake to decline at depths less than five meters. Agguss (1971) reported similar limiting conditions in Beaver Reservoir, Missouri, only at shallower depths. In both instances the invertebrate population was limited by wave action causing erosion of bank deposits and settling of these sediments in the shallow areas near the shoreline.

The vegetation of the inundated reservoir basin has been reported to affect benthic fauna distribution. Agguss (1971) reported newly inundated areas of a reservoir containing herbaceous plants to be more productive in bottom fauna than a forested area, presumably due to the more rapid decay of herbaceous material than trees. Ioffe (1961) suggested reservoir drawdown and subsequent terrestrial plant growth will increase benthic fauna production after the area is inundated again.

It is evident from the above discussion that bottom fauna are limited primarily to the littoral zone of the lake. Regions lying below the thermocline will have reduced benthic fauna production. A littoral zone containing macrophyte growth will have a higher productivity of bottom fauna than a littoral zone devoid of macrophytes.

The importance of the zooplankton and bottom organism production to a reservoir is the role they play as fish food. Reservoirs rich in these types of fauna will offer an abundance of fish food, reservoirs with low production of zooplankton or benthic fauna will naturally have less available fish food. A paucity of bottom fauna may be reflected in a slow growth rate of fish in the reservoir.

RESERVOIR FISHERIES

Fishery Development

Fishery development in a reservoir following impoundment can be accomplished by two basic mechanisms. The first is fishery development from the endemic fish of the river basin. The second is from stocking programs of desirable sport fish conducted by local or state fisheries organizations.

Campbell and Funk (1953) reported the dominance of a river species of fish in a reservoir is dependent upon numerous factors: initial abundance of the species in the river, spawning habits of the species, life span of the fish, season and rate of filling the reservoir, fluctuations in reservoir water levels, time required for the initial brood of the fish in the reservoir to reach sexual maturity and produce a second brood. Losses or decline of a fish population in reservoirs resulting from one or more of these factors has been reported by numerous authors.

Patriarche and Campbell (1957) reported the following fish as being unable to become established in Clearwater Lake following impoundment of the Black River, Missouri: small mouth bass, rock bass, grass pickeral, hog sucker, and spotted sunfish. These authors listed lack of spawning success and mortality of young to be the major causes of the failures. The channel catfish did not become well established in Clearwater Lake until four years following its impoundment. The authors attributed this slow development to be due to small initial catfish-brood stocks and slow sexual maturity of the catfish. Carlander (1969) listed the average age of sexual maturity in the channel catfish to be from four to six years.

Elrod and Hassler (1969, 1971) reported slight declines in the following fish species in the first six years of impoundment of Lake Sharp, South Dakota: northern pike, goldeye, carp, river carpsucker, blue sucker, smallmouth buffalo, largemouth buffalo, and shorthead redhorse. They attributed the decline in fish numbers to lack of spawning success and increased competition for food especially among the forage fish.

Numerous river fish have been reported to be capable of adapting to a reservoir environment. Patriarche and Campbell (1957) listed the following species successful in being able to make a transition from Black River, Missouri to the reservoir environment of Clearwater Lake: largemouth bass, white crappie, bluegills, longear sunfish, green sunfish, channel catfish, black and yellow bullheads, carp, golden redhorse, black sucker, pealip sucker, and gizzard shad. There are undoubtly many other species that are capable of the same transition.

Fish Growth and Productivity

If a fish species is successful in becoming established in a reservoir, it usually experiences enhanced growth rates following the first few years after reservoir filling. This is primarily due to the nutrients released from the inundated reservoir soils and the decay of basin vegetation. If other environmental conditions are not limiting the increased nutrients stimulate algal productivity. This increase in biomass is passed up the food chains to the fish, and results in a net increased fish growth rate during this period. Patriarche and Campbell (1957) found increased growth rates of warmouth, bluegill, green sunfish, and longear sunfish in the first year of impoundment of Clearwater Lake, Missouri. They also found relative growth rates of these fish to be higher in reservoir than in the river. Channel catfish experienced increased growth rate in two new Oklahoma reservoirs, (Jenkins and Leonard, 1952). Hassler (1969) found phenomenal growth rates of northern pike in the first six years of impoundment of Oahe Reservoir, South Dakota. He found average length of northern pike at the end of the first year of growth to be approximately 600 mm (23.6 in.) and at the end of the fifth year to be approximately 1000 mm (39.4 in.). This was higher than any other recorded northern pike growth rate for United States or the world. Ellis (1937) reported that the increase in productivity after inundation was followed by a subsequent reduction in fishery productivity.

After a reservoir has increased in age, and the initial increase in productivity declined, the growth rate of fish will be indicative of the biological productivity occurring in the lower trophic levels of the food chain. It has been shown previously that researchers were not able to establish a definite correlation between primary productivity and fish yield. It is generally recognized however, that higher productivity of algae and the other members of the food chains will result in increased growth rates of the fish. The clear correlation between primary production and fish yield is obscured by the complex interrelationships of the aquatic food web.

If a primary food of a fish population is missing in the trophic structure of the reservoir the growth rate of the fish will likely decrease. White bass are reported to be primarily predators on shad populations in reservoirs. Ruelle (1971) found a decline in the growth rate of white bass in Lewis and Clark Lake, South Dakota, and attributed it to a decline in the forage fish population in the lake. He also cited work by (McNaught and Hasler, 1961). These authors found white bass populations inhabiting Lake Mendota, Wisconsin were primarily zooplankton feeders, but that their growth rate was relatively low. Ruelle also cited work by Richardson and Rutledge (1961), who found growth rates of white bass accelerated by stocking of gizzard shad in a southern reservoir.

Olmsted and Kilambi (1971) discussed various environmental factors that seemed to affect feeding habits of the white bass in Beaver Reservoir, Arkansas. They found both immature and adult white bass preferred threadfin shad as a primary diet. This was altered somewhat by season. In the spring, insects were the predominant diet of the immature because they were too small to feed on the forage fish. The adults diet in the spring was composed of approximately 45% insects. This was caused by a decline in the shad population following a winter kill. Unfortunately the changes in the white bass diet were not correlated with growth rates.

Stocking programs have to be initiated to develop a reservoir sport fishery if native sport fish fail to become established following impoundment. The stocking programs can be either of two types; put-and-take, and initial stocking followed by successful natural reproduction of the planted species in the reservoir. The rainbow or brook trout are good examples of a put-and-take fishery. These two species are generally incapable in reproducing in a reservoir. A permanent trout fishery will then necessitate annual stocking in the reservoir. Walleye, channel catfish, and smallmouth bass have been stocked in some reservoirs and have been able to establish a naturally reproducing population. The ability of either planted fish or native fish to have continued spawning success in a reservoir is variously affected by environmental conditions developing within the reservoir.

Fish Spawning

Perhaps the most significant factor listed as regulating fish spawning in a reservoir is water level fluctuation. Hassler (1969) observed increased year class strength of northern pike in Oahe Reservoir, South Dakota, associated with a rise in water level in the reservoir. Other authors reported littoral spawning grounds of fish limited or completely eliminated by reservoir drawdown. For this reason water level fluctuation was used as an early management tool in reservoirs to suppress undesirable fish species (Bennett, 1970).

Sediment accumulation has been reported to limit spawning in a reservoir. A reservoir serves as a settling basin for river sediments, and generally decreases sediment load downstream from the reservoir. Symons, Weibel, and Robeck (1969) noted a decline in turbidity in Lake Francis Case, South Dakota from 400 - 500 JTU at the headwaters to 35 JTU near the dam. Wright and Soltero (1973) recorded a 60 fold decrease in turbidity from the headwaters to the dam in Bighorn Lake, Wyoming. These sediments can seriously limit natural fish spawning in the reservoir. Anon (1969) reported sediment accumulations in the upstream end of Boysen Reservoir, Wyoming as reducing available sport fish spawning habitat. Hassler (1968) found up to 100% mortality of northern pike embryos from sediment deposition in Oahe Reservoir, South Dakota. This mortality occurred when sediment deposition rates exceeded 0.5mm/24 hours. The sediment problem in Oahe Reservoir was caused by wave action causing shoreline erosion and subsequent deposition of this material in the shallows.

Miscellaneous Limiting Factors

Inter-(between species) and intra-(within a species) specific fish competition has been found to limit fish in a reservoir. Hushagen (1973) found that the planting of legal size largemouth bass in Merle Collins Reservoir, California, caused the stocked year class of fish to dominate the fishery for several years. Forage fish failed to become established in the reservoir, causing the largemouth bass to use their own young primarily as food. Subsequent decline of the largemouth bass population was attributed to interspecific competition with small mouth bass and over exploitation. Previous mention has been made of the interspecific competition of forage fish in Lake Sharpe, South Dakota, as causing a decrease in their numbers. Interspecific competition between the feeding activities of rough fish and spawning of sport fish was reported in Boysen Reservoir, Wyoming (Anon, 1969); and Atwood Lake, Ohio (Wright, 1954). The tendency for forage fish to become over abundant in a reservoir has prompted some fisheries personnel to recommend commercial fisheries operations for the impoundment (Patriarche, 1952).

Macrophyte development in the littoral zone offers an abundant food supply for fish as well as shelter. Martin and Campbell (1953) found a very abundant year class of bluegills in Clearwater Lake, Missouri, coinciding with development of very dense growths of pondweed in that year.

Fish are limited in their distribution by dissolved oxygen. Summer stratification and hypolimnion oxygen depletion will limit fish to the epilimnion.

DAM DISCHARGES

Dam construction in a river creates an artificial stream flow downstream from the reservoir. Water quality is perceptively increased from a suspended solids viewpoint because of the sedimentation occurring in the reservoir. In general, dam releases moderate the downstream temperature regime by lessening cooling in the winter and warming in the summer.

The decrease in suspended solids in a reservoir from the upstream area to the dam has been previously discussed. The sediment deposition in a reservoir causes the water discharged from the dam to be considerably clearer than river water upstream from the reservoir. Temperature moderation was noted by Pfitzer (1954) in the Wataugo Tailwaters in Tennessee. Before dam construction temperature fluctuations in the river ranged between 32 and 85 degrees F. Following dam construction, the downstream temperature ranged between 39 and 65 degrees F.

Other factors associated with dam discharges have been noted as being detrimental to downstream fisheries. Low temperatures, low dissolved oxygen concentrations of discharged water, as well as flow fluctuations have caused numerous problems in the tailwaters sections of many dams.

The temperature regime downstream from the dam will be dependent on the level of water withdrawal from the reservoir. Multilevel withdrawals help to alleviate some of the problems associated with water temperature.

The low temperature water released through low level intakes severely alter a downstream aquatic habitat. Pfitzer (1968) compiled information concerning 32 dam projects in the United States. All of the impounded streams possessed warm water fisheries prior to impoundment. Only one of the 32 tailwaters was reported to presently sustain a warm water fishery. Twenty-seven of the 32 had been developed into a trout fishery, and the remaining four had virtually no fishery at all. Pfitzer reported the work of Eschmeyer and Smith (1942) who found that the cold water released from Norris Dam, Tennessee, prevented spawning of the warm water fish species. This was the main reason advanced for the loss of the warm water fishery in the other tailrace areas. The four tailwaters that had no fishery were the result of poor project designs. In these, the volume of winter stored water above the penstock intakes was sufficient to preclude any spawning of the warm water fish, but insufficient to maintain a year round trout fishery.

Pfitzer (1968) noted that low dissolved oxygen concentration in the hypolimnion water also exerted an effect on the downstream fisheries. If the tailwater of one dam formed the headwaters of another reservoir pool, as in many TVA and Missouri River impoundments, reaeration of the water was very slow and inefficient. This condition contributed to adverse conditions in some of the tailwater fisheries. Lucas (1971) also noted the decline in macroinvertebrates downstream from a newly impounded reservoir. He attributed this decline to low dissolved oxygen releases and water flow fluctuations.

The nutrients trapped in the hypolimnion waters during the summer stratification may be discharged through withdrawal of the hypolimnion water (Wright and Soltero, 1973). These nutrients have been reported to increase the eutrophication potential downstream from the reservoir (Neel, 1963).

One of the most critical factors reported in the literature in downstream habitat is the amount of water released from the dam and the fluctuations in the releases. The amount and timing of water discharged from a dam is largely dependent upon the use of the reservoir and dam.

Severe fluctuations in water flow from a dam have been associated with hydroelectric operations. During times of peaking power requirements, flows are very large. The releases are drastically cut, however, after power needs wain.

The above situation occurred on the North Platte River between Kortes Dam and Pathfinder Reservoir, Wyoming (Anon, 1964). Historically this section of the North Platte River had an excellent trout fishery. Flows associated with the river reach averaged 1500 cfs (1914 to 1962). Minimum flows occurred in the winter and ranged from 250 to 450 cfs. United States Fish and Wildlife Service recommended flows from the Kortes Dam not be less than 200 cfs, and changes in the instantaneous releases be made gradually. After construction of Kortes Dam, however, minimum releases occurring throughout most of the year were from 8 - 10 cfs. This seriously depleted the trout fishery by curtailing food production, destroying adequate cover, exposing spawning and riffle areas, and decreasing the size of holes in the river. The decreasing of hole size caused an elevation in water temperature incompatible with trout survival.

Serious fish kills on the Republican River, Kansas, were reported when all water was diverted from the natural river channel by the Superior - Courtland Diversion Dam (Anon, 1961). Many highly prized catfish were killed as a result of these diversion procedures.

Beneficial uses of flow regulation were reported by other authors. A sport fishery was practically nonexistant on the Wind River prior to construction of the Boysen Dam. Turbidity was the major cause of the limited fishery. Construction of the Boysen Dam decreased stream turbidity because of sedimentation within the reservoir. Flow schedules compatible with downstream fisheries needs were implemented.

Flow schedules established a minimum of 250 cfs for release, with releases being made gradually so surface elevation changes of the river downstream did not exceed 0.5 feet in a six hour period. These conditions created good conditions for a trout fishery which now exists in the Wind River downstream from Boysen Dam.

Wesche (1973) conducted flow experiments on two small Wyoming streams (average daily flow, 30 cfs). He found the greatest loss of hydrologic parameters (water depth, veolocity, cross-sectional area, wetted perimeter, hydraulic radius, top width, total surface area, surface area having a velocity of one foot per second, surface area with a depth of 0.5 feet or greater, and available brown trout cover) occurred when the flow of the two streams fell from 25 to 12.5% of their average daily flow. The author recommended that investigations be conducted on larger streams to determine if his findings on reduction of trout habitat is applicable to those situations.

It is recognized that the status of a tailwater fishery resource is dependent upon flow release patterns from the dam. The examples of Kortes Dam and the Superior Courtland Diversion Dam above showed how low flow releases can seriously affect a tailwater fishery. Enhancement of a downstream fishery was also noted in the operational procedures of Boysen Dam.

While the reservoir operational procedures are designed to meet the needs of the interested agencies (irrigation, storage, hydroelectric), it must also be recognized that creation of a synthetic stream flow from the reservoir affects the downstream fisheries.

The engineering aspects, especially of water intakes (multilevel vs single level) and flow release schedules, therefore, should be established not only by the dam builder, but also those agencies interested in maintaining the reservoir and downstream fisheries. This will necessitate compromises between water use demands for the impounded water and fishery development.

Pfitzer (1968) commented:

> "With the engineering knowledge and techniques available today, there is no reason why the design of any high dam cannot be equipped with enough flexibility in the operation to permit some modification of the fishery management programs of the reservoirs and tailwaters as the socioeconomic changes demand it. Our thinking should be geared to designs that accomodate the greatest range in fishery management potential within the realm of economic feasibility."

While commenting primarily on high multipurpose dams, Pfitzer's comments seem applicable to any type of dam project.

SUMMARY

Numerous factors outside and inside a reservoir contribute to regulating the water quality and biota of the impoundment. The preceeding discussion described how each factor affects reservoir limnology. Food chain relationships were explained which showed the importance of algae and macroinvertebrates to reservoir fish productivity. A discussion of the effects of dam discharges on downstream biota was presented. The basic factors controlling reservoir limnology developed in this appendum were correlated to data available for the Powder River Basin, Wyoming, to formulate predicted water quality changes that may result from proposed impoundments.

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APPENDIX V

AN INVESTIGATION OF THE PHYSICAL THERMAL EFFECTS OF ONCE-THROUGH COOLING FOR STEAM ELECTRIC PLANTS ON THE UPPER MISSOURI RIVER

A Joint Utility - EPA Study Performed
In Conjunction with the NGPRP

February, 1975

Appendix V

Acknowledgements:

Principal Investigator: Northern States Power Company
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February, 1975

PREFACE

The reader is referred to Section 316(a) of Public Law 92-500 (The Federal Water Pollution Control Act as amended in 1972) which reads as follows:

> "Sec. 316. (a) With respect to any point source otherwise subject to the provisions of section 301 or section 306 of this Act, whenever the owner or operator of any such source, after opportunity for public hearing, can demonstrate to the satisfaction of the Administrator (or, if appropriate, the State) that any effluent limitation proposed for the control of the thermal component of any discharge from such source will require effluent limitations more stringent than necessary to assure the projection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water into which the discharge is to be made, the Administrator (or, if appropriate, the State) may impose an effluent limitation under such sections for such plant, with respect to the thermal component of such discharge (taking into account the interaction of such thermal component with other pollutants), that will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water."

This report is not considered to have fulfilled the requirements of that section nor was it designed to. Section 423.15 of Title 40, Code of Federal Regulations, specifies that new sources (steam electric power generating plants of greater than 25 megawatts rated generating capacity) shall discharge no heat from the main condensers except where the blowdown temperatures do not exceed the lowest temperature of the cooling water prior to addition of make-up water (paraphrased). The report is, however, considered to have initiated an investigation of once-through cooling in the spirit of these laws and regulations.

SUMMARY

This study analyzed the discharges of once-through cooling waters from hypothetical power plants (1,000 to 4,000 megawatt range) sited along the Upper Missouri River. The analysis was limited to modeling the temperature rises caused by the discharges. Results of model studies for all study sites show rapid mixing and near-field return to within 3° F and 5° F of ambient temperatures. These results have assumed no atmospheric cooling. For the submerged discharges even under the most adverse flow conditions, the 5° F isotherm under low flow conditions and maximum plant discharge flow extends less than 350 feet downstream. These studies show that for a large facility (up to 4,000 megawatts) cooling water temperatures of 25° F above ambient can be reduced rapidly to 5° F or less above ambient through proper selection and orientation of the cooling water discharge.

This study was undertaken to see if the alternative of further once-through cooling along the Missouri River was an alternative worthy of additional impact analysis. The results of this modeling effort indicate that additional research concerning the environmental impact of the once-through cooling alternative may be warranted. It should be noted that similar needs exist for further research into increased efficiencies for recirculating cooling systems, for water treatment processes that prolong the useful life of recirculated waters, dry and wet-dry cooling alternatives.

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An Investigation of the Physical Thermal Effects
Of Once-through Cooling for
Steam Electric Plants on the
Upper Missouri River

INTRODUCTION

The Northern Great Plains Resources Program (NGPRP) is a joint effort by the Federal and State governments, as well as industry, environmental groups, and other private individuals, all of whom are concerned with the effects of coal development in the Northern Great Plains. They are concerned that the Nation has an adequate supply of energy, and at the same time, would like to be assured that energy developments proceed in a way that minimizes adverse environmental and socioeconomic impacts.

The primary objective of the Northern Great Plains Resources Program is to provide information and thus an analytical framework within which a comprehensive analysis may be made to place the potential impacts of coal development into perspective. The Program is designed to assist the people of the Northern Great Plains and the Nation in the management of the natural and human resources of this region. Such management has been facilitated under the NGPRP by providing a communication and coordination link among organizations and activities dealing with the future development of the region so that they might function more efficiently and effectively.

The NGPRP included a series of investigations and studies conducted by Work Groups in seven subject matter categories: Regional Geology; Mineral Resources; Water; Atmospheric Aspects; Surface Resources; Social, Economic, and Cultural Aspects; and National Energy Considerations. The geographic area which these seven Work Groups studied included portions of Montana, Wyoming, North Dakota, South Dakota and Nebraska. The physical resource analysis focused on the coal fields of the Wasatch and Fort Union Formations of the Northern Great Plains Coal Province. Other analyses generally included this area but, in selected instances, covered a larger or smaller portion of the States in order to treat important issues and effects of coal development.

The conversion of coal to electricity in the Northern Great Plains has been intricately linked to water supplies. Historically, without sufficient water, coal conversion would occur elsewhere. Today competition for water and the resulting lack of a reliable source of water may improve the competitive economics of dry and wet-dry cooling. High surface water costs may place pressure on ground water sources and high water costs may affect the rate of coal development. Water diversions for coal development and electric power generation will have to compete with existing uses and other future growth in the region. Some of the major questions concerning water which have been identified by NGPRP Study Teams are:

- **What are the existing water resources in the NGP and, how are they being used?**
- **What will the future demands on these resources be?**
- **How much water is available for energy development?**
- **What will water cost?**
- **What will be the impacts of increased water used for energy resource development?**

A primary surface water resource in the NGP area is the Missouri River. It is clear that any future plans for conversion of coal into electric power in the area would include some relationship to the surface waters of the Upper Missouri River system. The question then arises as to what the quantitative nature of the relationship would be if the water use was for cooling. In a sense, this analysis was performed to examine a potential to move coal to water rather than water to coal. Assuming that there will be an increase in the competition for water, the analysis plays a role in assuring that a scarce, competitive resource is optimally used without waste.

Electric power generating plants which produce power via thermodynamic processes require significant amounts of condenser cooling water[1]. Thus the possibility of operating large power plants in the NGP area can appear to be in conflict with the potential for critical water shortages identified. However, the large amounts of water used in condenser cooling are not consumed in their entirety, nor are the waters totally unfit for further use. Water may be used in one of two primary ways in the plant cooling cycle:

- Recirculated in a closed-loop cooling cycle
- Circulated only once through the condenser and immediately discharged back to the water body

Both of these cooling modes require the loss or consumption of a certain percentage of the cooling water, but it is the latter, "once-through" cooling mode, that in absolute terms would consume the least amount of water by a substantial margin. It, therefore, has applicability in any long-range water management considerations for the Missouri River area where water supply and competitive uses were thought to be dominant factors.

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1. A 1,000 megawatt coal-fired steam electric plant requires approximately 700 cubic feet per second (pass through) for condenser cooling, assuming a temperature rise of 25° F. Additional makeup water requirements for various cooling options are (based on 1000 MW): Wet Cooling Towers 14 to 19 cfs; Cooling Ponds 20-25 cfs; Once-through 1000 cfs; Dry Cooling 5 cfs. (See "Feasibility of Alternative Cooling Systems for Power Plants in the Northern Great Plains" (EPA, Region VIII, October, 1974) and this Subgroup Report).

Therefore, it was deemed appropriate by both the EPA - NGPRP Program Office and the sponsoring utilities to undertake a basic study to identify the physical thermal effects using the once-through process as the primary cooling mode for large-scale electric power facilities on the Missouri River. This alternative was included by the NGPRP in an attempt to cover all feasible alternatives.

It must be noted, however, that this study is done within the same philosophy of the NGPRP: It is future profile oriented and DOES NOT REPRESENT PLANS FOR ELECTRIC POWER DEVELOPMENT ON THE PART OF THE GOVERNMENT OR THE POWER INDUSTRY[1].

This information is intended, as with other reports of the NGPRP, only as a guidance document and decision-making tool to help measure what future development effects may be.

STATEMENT OF FINDINGS

This study indicates that, with respect to the quantitative evaluation of various hypothetical power plant sizes, assumed river conditions and plant sites, once-through cooling does appear to produce limited downstream temperature rises according to the models reviewed and used. No attempt was made to define or evaluate possible environmental/biological effects. This report suggests that the predicted rapid dispersion of heat from such discharges warrants the study of the other aspects of the once-through cooling alternative such as the biological effects of the discharges.

STUDY APPROACH

The problem, as stated earlier, was to determine the physical thermal effects of using once-through cooling for electric power plants on the Upper Missouri River. That portion of the river is not a uniformly moving body of water, due to substantial construction of dams and reservoirs for flood-control, agricultural, and power production purposes. Therefore, one could not simply select a single hypothetical site on the river bank and allow this to serve as a model. Rather, it was felt that several representative hypothetical plant sites should be selected to provide a range of data on the river for both the open (rapidly-flowing) and reservoir (slowly-flowing) conditions. A total of five (5) such sites were selected.

Having selected the sites, each was defined only in sufficient detail as to permit possible cooling water inlet and outlet configurations to be assumed. Then, flow parameters representing

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1. An earlier joint industry/government study of the region, "The North Central Power Study", was widely mis-read as constituting a "plan" for massive power facility construction in the NGP. Neither the EPA nor the power industry is interested in having similar mis-understandings applied to this report.

typical and adverse river or reservoir conditions, appropriate cooling water outfall parameters, and typical meteorological conditions were modeled by use of a computer. Hypothetical cooling water discharge plume configurations were thus developed which represent typical and adverse conditions for each site.

STUDY AREAS

Figure #1 shows the location of the following five hypothetical plant areas which were selected for this study:

Area 1: East side of Oahe Reservoir in Township 131N, Range 79W, approximately 20 miles southwest of Linton, North Dakota.

Area 2: South side of Missouri River in Township 143N, Range 81W, approximately 2.5 miles southeast of Washburn, North Dakota.

Area 3: South shore of Garrison Reservoir (Lake Sakakawea) in Township 146N, Range 88W, approximately 15 miles north by west of Beulah, North Dakota.

Area 4: West shore of Lake Sakakawea in Township 151N, Range 92W, approximately 7.6 miles south southeast of Newtown, North Dakota.

Area 5: West shore of the west leg of Fort Peck Reservoir in Township 25N, Range 40E, approximately 24 miles south of Glasgow, Montana.

Having selected five representative areas, each area was examined to select a specific plant site having known parameters that could be used in the model. The criteria used in selection of these five specific sites are as follows:

1) Must reasonably represent a site that would have the practical features a utility might look for in establishing a new power plant, such as rail line in the vicinity, access by road, available land for plant and appurtenances, nearby community for construction crews, etc.

2) Shoreline features that are either straight and roughly parallel with stream flow, or a small peninsula that protrudes into the water body.

3) Bottom contours sloping rapidly from shoreline into deeper water (to facilitate thermal mixing).

4) Representative sections of both open, flowing reaches of river and slower moving reservoir conditions.

Using these criteria, the specific plant sites which were selected from the hypothetical plant areas shown in Figure #1 are these:

Plant Site 1: (Figure #2) Located in Emmons County, North Dakota, approximately 2.5 miles north northeast of Fort Yates on the east bank of the Oahe Reservoir. The reservoir is about 12,000 feet wide at this site. Topographical maps of the site show this site and points downstream to have steeper slopes into the water than points upstream. The shoreline at this site extends nearly straight downstream. The bottom width of the usable reservoir is about 3500 feet. Elevation of the reservoir bottom is between 1580 feet and 1585 feet MSL.

Plant Site 2: (Figure #3) Located in Oliver County, North Dakota, approximately 2.5 miles southeast of Washburn, on the southwest side of the Missouri River almost directly opposite the mouth of Turtle Creek. The river at this site is about 2070 feet wide and averages four feet deep. The main channel near the west bank is about 800 feet wide and averages ten feet deep. The exit if the proposed discharge canal is located about 300 feet downstream from the confluence of Turtle Creek. The shoreline is straight near the discharge point and downstream, and the river is uniform.

Plant Site 3: (Figure #4) Located in Mercer County, North Dakota, and about 15 miles northwest of Beulah on a peninsula on the south shore of Lake Sakakawea (Garrison Reservoir). The reservoir at this site is about 5.3 miles wide and has a depth of over 100 feet 400 feet from the shore. Because of the depth of the reservoir at this site, it is ideal for a submerged discharge. The peninsula itself provides a good divider between an intake and discharge mixing area. Because of the depth of Lake Sakakawea in the nearby area, there are several sites in the vicinity which are well represented by Site 3.

Plant Site 4: (Figure #5) Located in Mountrail County, North Dakota, approximately 7.6 miles south southeast of Newtown, and 9000 feet north of the Fort Berthold Indian Reservation. The reservoir bottom near Site 4 is rugged and not as suitable for a submerged discharge as at Site 3. There are several low elevation areas which were lakes before the filling of the reservoir. Using two such areas which are separated by an underwater hill, the intake and discharge can be separate to avoid recirculation.

Plant Site 5: (Figure #6) Located in Valley County, Montana, in the west shore of the west leg of Fort Peck Reservoir, approximately 24 miles south of Glasgow. There are several potential sites in this area having almost the same physical conditions but varying amounts of area for plant facilities. Because of the shallow slope of the reservoir bottoms, the submerged discharge port is about 600 feet away from the shore line. The peninsula could separate the intake structure from the discharge.

Information gathered for each site included the water body bottom contours, water temperature, water surface elevations, flow rates and site topography. Information gathered is from the United States Army Corps of Engineers and from the Water Resources Data for North Dakota manual published by the United States Geological Survey (USGS)[1]. Since information such as temperature stratification is not available in the literature, results presented in this report must be considered preliminary and additional studies of the various plant sites and water body characteristics would be required for detail evaluations. Since the modeling procedure is assumed to be conservative, the authors feel that stratification of the degree that might be expected at the sites will not affect the predictions.

The question has arisen as to whether it was difficult to find sites along the Missouri River which fulfilled the selection criteria. The investigators found that the five sites selected were representative of many other sites whose bottom and bank conditions were favorable for testing the prediction method.

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[1] Water Resources Data for North Dakota, 1972, Parts 1 and 2. United States Department of the Interior, Geological Survey.

COMPUTER MODEL

A chief consideration in the investigation is the phenomenon of plume mixing. It was sought to determine the plume mixing characteristics of the various discharge configurations and plant sizes at each site, thereby giving an indication of once-through cooling effects on the thermal regime of the water body.

A number of mathematical models are available for the prediction of thermal plume mixing. Almost all of the models are based on the assumption of a strong flowing jet discharging into a large ambient water body while a few allow a uniform velocity of the receiving water. Because sufficient knowledge of the mixing mechanism is lacking, none of the models allow for the speed of the receiving water to be greater than or equal to that of the effluent jet. All models used assume the ambient water body is infinitely large (i.e., all boundaries of the water body are infinite distances from the plumes and therefore have no effect on the flow or the process of mixing).

Submerged Discharges -

For this study the ROW Buoyant Jet model of Koh and Fan[1] was selected for submerged discharges. The original ROW Buoyant Jet model was modified to analyze single port and slot discharges in addition to multiple port discharges. In order to predict the discharge of multiple ports or slots in shallow water, this model was further modified by using the results of Jirka and Harleman[2]. A sub-program has been added to characterize the flow in the zone downstream from the surface impingement of the thermal plume. The model as modified appears in Appendix A. Jirka and Harleman state that results from the Koh and Fan model agree more closely with field measured data in the zone of the submerged plume than do results of their own model.

Surface Discharge -

For surface discharge, the PDS model of Shirazi[3] and Davis[4] was used. The PDS model is a three dimensional mathematical model

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1. R. C. Y. Koh and L. N. Fan, 1970. Mathematical models for the prediction of temperature distributions resulting from the discharge of heated water into large bodies of water. Water Quality Office, EPA.
2. G. Jirka and D. R. F. Harleman, 1973. The mechanics of submerged multiport diffusers for buoyant discharges in shallow water, Report No. 169. Department of Civil Engineering, MIT.
3. The investigators gratefully acknowledge the willing help of Dr. Mostafa A. Shirazi of the National Environmental Research Center in Corvallis, Oregon, in selection, modification, and use of the models used in this study.
4. M. A. Shirazi and L. R. Davis, 1974. Workbook of Thermal Plume Prediction, Vol. 2 - Surface Discharge, May, 1974. National Environmental Research Center, Office of Research and Development, U.S. EPA.

developed from Prych's model. Minor modifications were performed so that output is presented in dimensional values. A copy of the modified model is attached as Appendix B. Results of this model are valid only when the ambient flow speed is less than 70% of the effluent jet discharge speed.

The Motz-Benedict[1] model and Stefan's[2] model were also considered but were not used. Motz-Benedict model does not consider plume buoyancy. Stefan's model does not include a development zone[3]. Therefore, both of these models were rejected for use in this investigation.

Application of the models requires minimization of interference of the water body boundary with the thermal plume boundary. Through site selection, variation of discharge velocity interaction of the characteristic boundary of the thermal plumes with the boundary of the water body can be avoided or minimized.

In using these models, three uniform assumptions were made to simplify the analysis:

1. For each megawatt of electrical output the waste heat through the condenser was assumed to be 4000 BTU/sec.
2. Ambient water temperature was assumed to be 58° F, the normal high temperature of the Missouri River in the study region.
3. Generators would be 1000 MW size, with the possibility of more than one unit at each site.

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[1] L. H. Motz and B. A. Benedict, August, 1970. Heated Surface Jet Discharged into a Flowing Ambient Stream.

[2] H. Stefan, N. Hayakawa, and F. R. Schiebe, December, 1971. Surface Discharge of Heated Water. Environmental Protection Agency, Office of Research and Monitoring (Project #16130 FSU).

[3] Development zone is that distance, usually short, from the point of discharge to the point of full turbulent mixing.

DISCUSSION OF RESULTS

Plant Site 1 -

Normal water level elevation of the Oahe Reservoir is 1607.5 feet msl and can be managed from a low level of 1540 feet msl to a high level of 1617 feet msl. Record low water elevation for the Oahe Reservoir is 1600 feet msl. (The low water level is assumed for thermal plume calculations.) At a record low water level, the reservoir depth near Site 1 is 16 to 20 feet (based on a topographical map of the reservoir and river bottom cross section). The variation in water depth (from a minimum of about 35 feet), hampers selection of a discharge canal cross section which would provide satisfactory mixing at all combinations of plant load and water elevations. The 16 foot minimum water depth also restricts the size of submerged ports which could provide satisfactory mixing. A multiple-port diffuser is most adaptable to providing mixing within the limited depth available at Site 1.

River flow velocity at Site 1 is about 0.1 FPS and, therefore, negligible compared to the selected discharge velocity of 3.4 FPS. The ROW Buoyant Jet Model is applicable for analyzing a multiple-point diffuser at this location. Assuming an installation of four 1000 megawatt generating units at Site 1, the diffuser would comprise 600 individual ports, each 18 inches in diameter and spaced 5 feet center-to-center. Total diffuser length is 3,000 feet compared to the river width at this point of 12,000 feet. As shown on Figure 2, the diffusers are assumed to be aligned perpendicular to the shoreline and directed downstream. The ports are assumed to be approximately 15 feet below the record low water elevation and directed upward at an angle 20° from horizontal. There should be no bottom erosion because of the initial upward momentum plus rapid reduction in velocity. Figure 7 shows a cross section of a typical diffuser port and the resultant isotherms and plume boundary. Assuming an initial temperature rise (T) of 25° F, the 10° F T isotherm extends slightly more than 13 feet downstream with the 5° F isotherm extending approximately 20 feet downstream. At approximately 15 feet from the discharge ports, plume impingement at the surface is expected to result in a hydraulic jump which will induce the bottom wedge into the plume in the region immediately downstream. According to Jirka and Harleman, plume velocities are expected to decrease rapidly with discharge downstream, and since the jet is directed 20° above horizontal, bottom erosion would not be expected to present a problem.

The calculation results presented in Appendix C, and the cross section shown in Figure #7, apply for any cross section in the length of the diffuser. For example, if only one of the four units were operating discharge would be limited to 150 ports for a total diffuser length of 750 feet, but the cross section would be as shown in Figure #7.

Plant Site 2 -

Based on flow records for the Missouri River at Washburn and Bismarck, North Dakota, water elevation at Site 2 is estimated to vary from a low of 1650.5 feet msl at a flow of 16,000 cfs to a high of 1655.0 feet msl at a flow of 39,000 cfs. Average flow is 26,000 cfs with a corresponding stage of 1652.5 feet msl. The main channel at Site 2 approaches to within about 100 feet of the near shoreline. Therefore, most of the river flow is near the plant side of the river. Maximum river depth at low flow is approximately 12 feet. Average depth at normal flow is approximately 11 feet. Presuming discharge flow can be varied to some extent at low water flow such that plume projection into the main stream is optimized for mixing, an open channel surface discharge was chosen. The PDS Model of Shirazi was used for analysis of the discharge from the assumed 2,000 megawatt generating installation at Site 2. Calculational results are presented in Appendix C.

For reliable results from the PDS model, discharge canal cross section and orientation must be selected such that the ratio of river speed (S_r) to discharge speed (S_d) is less than, or equal to, 0.7 (S_r/S_d - 0.7). This is to assure that the thermal plume development zone does not interfere with the water boundaries. Because of the variation in the river level and the possibility that one of two units might be operating at any time, it is not possible to select a single canal configuration that will satisfy this condition at all times.

The selected canal width of 60 feet with a bottom elevation at 1648.5 feet minimizes interference of the plume with the river bed for most situations. The canal discharges perpendicular to the river flow.

With two 1,000 megawatt units operating, total plant condenser flow would be about 1425 cfs, resulting in a condenser rise of 25^{o} F. To insure proper mixing with one unit operating, circulating water flow would be adjusted down to 712 cfs to maintain the 25^{o} F Δ T. At higher river flows, even with only one unit in operation, greater discharge velocity (hence greater condenser flow) would be required to maintain proper mixing. Flexible pump operation could be designed into such a plant to provide one-unit operation with a condenser temperature rise of 15^{o} F at a flow of about 1200 cfs. Circulating water pump operation could then be adjusted based on river water elevation and the generating capacity in service. Variable pump operation is not assumed in the following examples:

> Model results show a temperature decrease from 25^{o} F above ambient at the mouth of the discharge canal to 10^{o} F above ambient within a short distance of the canal. Plan views of the plume for various river flows are shown on Figures 8, 9, and 10. For low river flow the distance is under 100 feet. At higher river flows the plume is swept downstream at a faster rate such that at high flow the 10^{o} F

isotherm extends 400 feet downstream. The length of the 5° isotherm is a maximum of 1,100 downstream at high river flow and a minimum of about 300 feet downstream at low-flow. As can be seen from the plum cross sections (Figures 11, 12, and 13), as the length of the 5° F isotherm increased it becomes thinner. For the average flow condition, the 5° F isotherm extends less than 1,100 feet downstream and reaches a depth of 10.4 feet at 170 feet downstream (Figure 12). At high river flow the 5° F isotherm extends an additional 200 feet downstream but, as shown in Figure 13, is thinner; reaching a maximum depth of 9 feet. Not all conditions of river flow and plant operation conform to the boundary conditions specified for the PDS mode.

At low river flow with two units in service, the thermal plume interacts with the river bottom (Figure 11). It is presumed, however, that the results obtained are valid since, (1) Development of the thermal plume has progressed such that the 5° F isotherm reaches maximum depth at approximately the point where the plume boundary hits the river bottom; and, (2) Presuming there was no interference, the 5° F isotherm extends only about 500 feet from the discharge point. Thus, after the plume interacts with the river bottom, it will develop two-dimensionally in the horizontal plane. While the model shows the 5° F isotherm extending 500 feet downstream, it is presumed that it will extend only slightly more than 500 feet downstream.

Plant Site 3 -

Normal pool elevation of the Garrison Reservoir is 1837 feet msl. The record low level since the reservoir was filled is 1836 feet msl. For this analysis a low level of 1830 feet msl was assumed. The reservoir bottom near Site 3 slopes rapidly away from the shoreline, reaching a depth of over 100 feet at less than 1000 feet from shore. Since information on stratification of the reservoir is not available, temperature and density distribution of the reservoir was assumed uniform. This is a conservative assumption since, if stratification did exist, mixing would tend to be more complete before the plume reached the surface.

The great depth available at Site 3 allows usage of eight-foot diameter discharge ports placed at a depth of 100 feet. Assuming a plant capacity of 4,000 megawatts, a total of eight discharge ports spaced 30 feet center-to-center would produce the results depicted in Figures 14 and 15. The ROW Buoyant Jet Model of Koh and Fan was used to calculate mixing from these submerged discharge ports. Figure 4 shows the orientation of the ports with respect to the plant.

Ports are arranged to discharge parallel to one another in a northeasterly direction at an angle of 25° from the horizontal and at an initial temperature rise of 25^{o} F above ambient. Total plant flow, assuming 4,000 megawatts capacity, is 2850 cfs. As shown in Figure 14, the plumes merge at approximately 70 feet (horizontal) from the discharge ports at about 40 feet above the bottom of the reservoir, to which point the 10^{o} isotherm extends. The 50^{o} isotherm extends about 110 feet downstream and about 85 feet above lake bottom. Initial velocity of the discharge jet is assumed to be about seven feet per second. Jet velocity should decrease to under three feet per second at a distance 50 feet downstream. At a distance 120 feet downstream and about 90 feet from the bottom of the reservoir the velocity at the plume center line has decreased to less than 1 FPS. Calculation results for Site 3 are shown in Appendix C.

Plant Site 4 -

Reservoir water levels at Site 4 are the same as described for Plant Site 3. Bottom profile of the reservoir near Site 4 is rugged and, near the shoreline, is too shallow a submerged discharge. Because there is little circulation in this bay-like area of the reservoir, a canal discharge would probably not provide adequate mixing under all circumstances. Approximately 4,000 feet east and 6,000 feet northeast of the plant site there exist two relatively deep areas (lakes, which existed prior to construction of the Garrison Dam) separated by a submerged hill. The discharge pipes are assumed to be placed in the northeasterly submerged lake at the bottom of the reservoir (approximately elevation 1760) and directed in a southeasterly direction to give the thermal plume sufficient initial momentum to carry itself into the main stream. The intake point, located in the deep area east of the plant would be separated from the discharge by a distance of several thousand feet and the intervening submerged hill. This configuration would induce a flow in from the main stream of the reservoir, thus avoiding recirculation of the discharged water.

Two 1,000 megawatt generating units were assumed at Site 4. Each unit would require two 7 foot in diameter discharge ports placed at 45 feet center-to-center (Figure #16). The four discharge ports would be placed at an elevation 1770 msl and about 60 feet below the surface at low pool elevation (Figure #17). The ports would be directed upward at an angle 15 degrees from horizontal and would have an initial discharge velocity of 9.25 feet per second. An initial temperature differential of 25^{o} F above ambient was assumed. The discharge water would mix rapidly with the surrounding lake water such that the maximum temperature would drop to 10^{o} F above ambient within 80 feet of the discharge port. At about 120 feet from the ends of the ports the temperature has decreased to about 5^{o} F above ambient. The results depicted on Figures 16 and 17 are based on Koh and Fan's FOW Buoyant Jet Model and are more completely described in Appendix C. A 2,000 megawatt plant is probably the upper size limit possible at this site for the intake and discharge configurations assumed. Beyond this size, recirculation of the mixed discharged water would probably occur.

Plant Site 5 -

Normal pool level of the Fort Peck Reservoir is 2,234 feet msl. According to reservoir design data, water level varies from a high of 2,250 feet msl (16 feet above normal) to a low of 2,160 feet msl (74 feet below normal). This extreme fluctuation in pool level (90 feet) imposes economic penalties against once-through cooling at Site 5. These economic questions along with other technical considerations are discussed in following pages. Presuming that economic incentives for once-through cooling overcome economic disadvantages of other technical considerations for this site, the following study conditions were assumed: a 1,000 megawatt generating unit with a discharge located over 6,000 feet from shore and placed at a depth of about 7 feet below low pool elevation was studied using Koh and Fan's ROW Buoyant Jet Model. Results for the thermal plume analysis are shown in Figures 18 and 19 for the low water "worst case" condition. The two 7 foot diameter discharge ports are assumed to be 50 feet apart and are directed upward at an angle 10 degrees from horizontal (Figure 18). Initial temperature is assumed to be 25° F above ambient and discharge velocity is assumed to be 9.25 per second. The 10° F isotherm is reached at approximately 80 feet from the end of the discharge ports and the 5° F isotherm is reached at about 120 feet from the end of the ports. A tabulation of results for low, normal, and high pool levels appears in Appendix C.

ECONOMIC AND PHYSICAL IMPACTS OTHER THAN THERMAL

This study did not consider the impacts on the environment of such discharges nor did it consider the economic feasibility of the five open cycle cooling schemes. Open cycle cooling would not be used if some other form of operation were more economically acceptable. The requirement presumed for the thermal plume analyses, without regard to economics, was to discharge full plant cooling water flow and mix it as rapidly as possible with the receiving water. Some economics problems can be offset through selection of sites with advantageous topography. In Site 4 and Site 5, the need for lengthy intake and discharge pipes could be eliminated. A nearby site could be found where the reservoir bottom sloped more rapidly to the depths required.

At Site 5, an analysis would be required to determine whether it is more desirable to set the slant condenser 60 feet below high water level to avoid the need for auziliary pumping at low water elevations. Constructing the plant at this low elevation would require great expense for excavation and probable dewatering. Conversely, installation of auxiliary pumps plus energy requirements to raise the water through the condenser if it were placed above high water elevation would require detailed investigation. Presuming that low pool elevation would occur relatively infrequently, installation of auxiliary pumps for infrequent use would probably be less expensive than construction of the plant at such a low elevation. In either case, costs would be compared with those of alternative cooling systems before the choice was made.

The cost of constructing railroad and transmission access to these sites would also require comparison to the cost of piping make-up water to a closed cycle cooling system away from the river and closer to existing roadway, railroad, and transmission networks.

SUMMARY

Results of model studies for all study sites, show rapid mixing and near-field return to within 3° F and 5° F of ambient temperatures. These results have assumed no atmospheric cooling. For the submerged discharges (Sites 1, 3, 4, and 5) even under the most adverse flow conditions, the 5° F isotherm under low flow conditions and maximum plant discharge flow extends less than 350 feet downstream. These studies show that even for a large facility (up to 4,000 megawatts) cooling water temperatures of 25° F above ambient can be reduced rapidly to 5° F or less above ambient through proper selection and orientation of the discharge.

Logical follow-up studies to this investigation would include identification of biological impacts, far-field thermal studies, detailed cost analysis and engineering studies for the identified sites, and identification of other sites near those identified in this report which would be similar in their acceptability from the standpoint of engineering and environment considerations.

ILLUSTRATIONS

Drawings Index for Missouri River Basin Thermal Study

1. Upper Missouri River Basin Area (site map)
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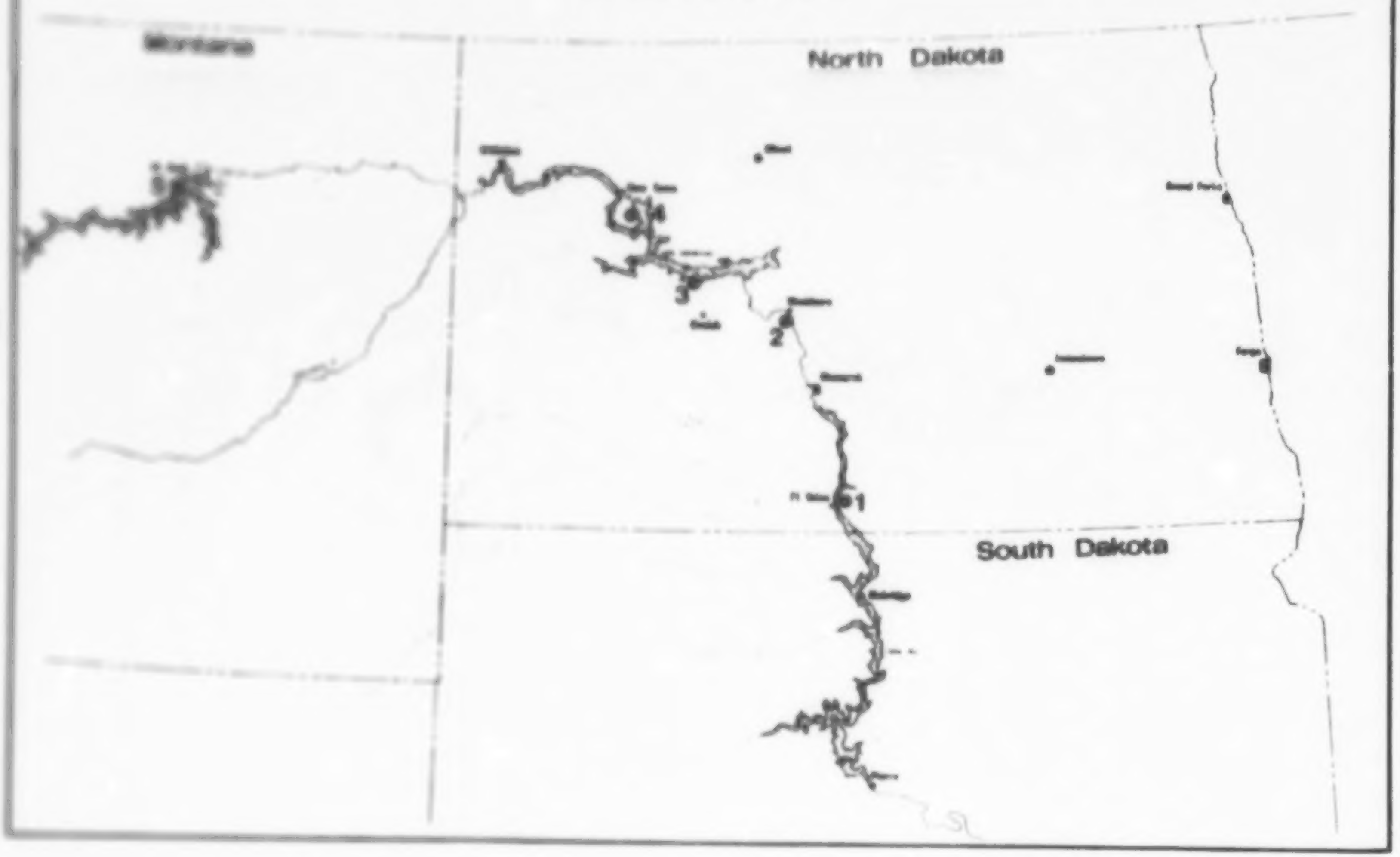
Upper Missouri River Basin Area

Thermal Study Sites


Montana
North Dakota
South Dakota
4
3
2
1

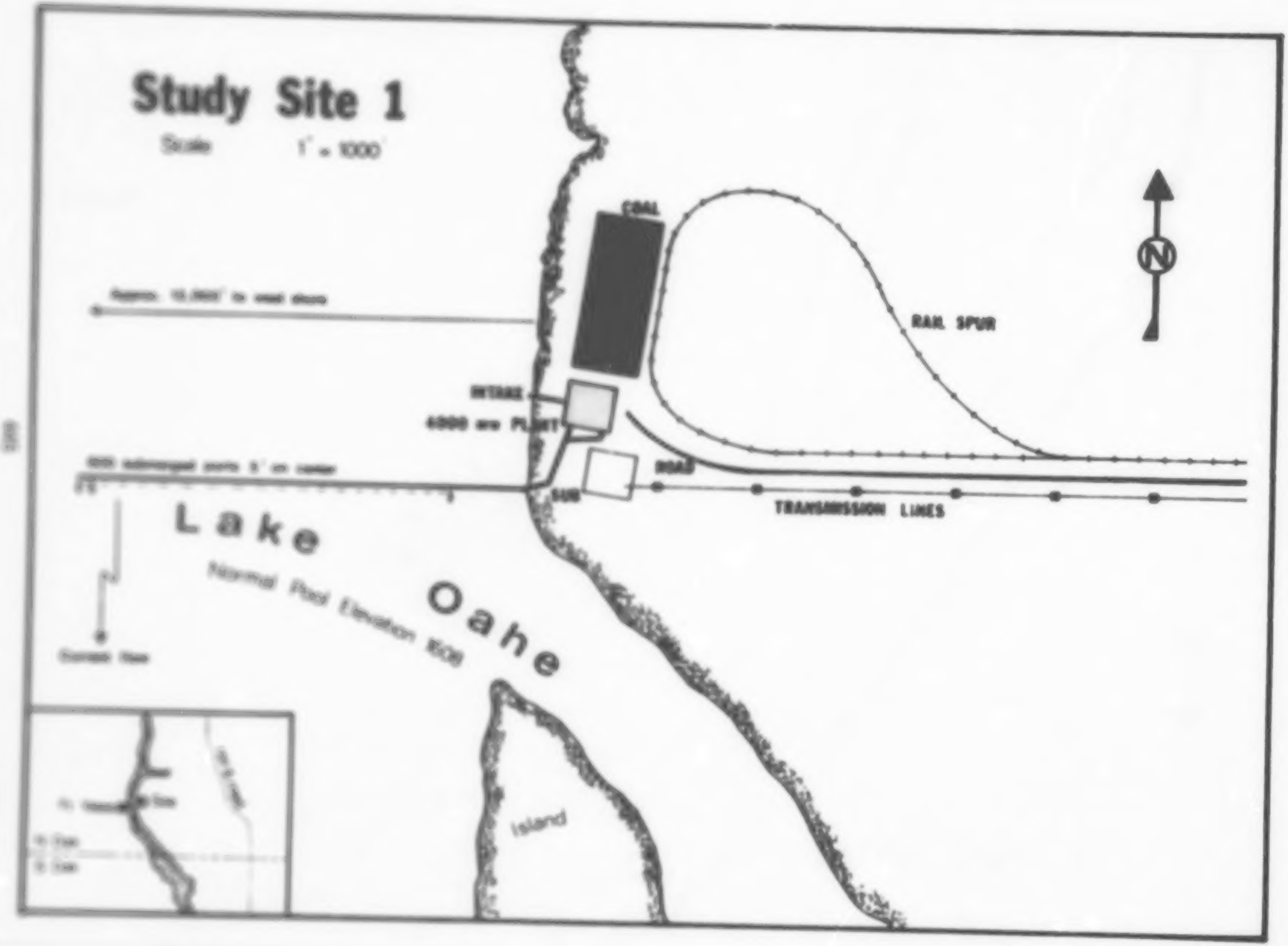
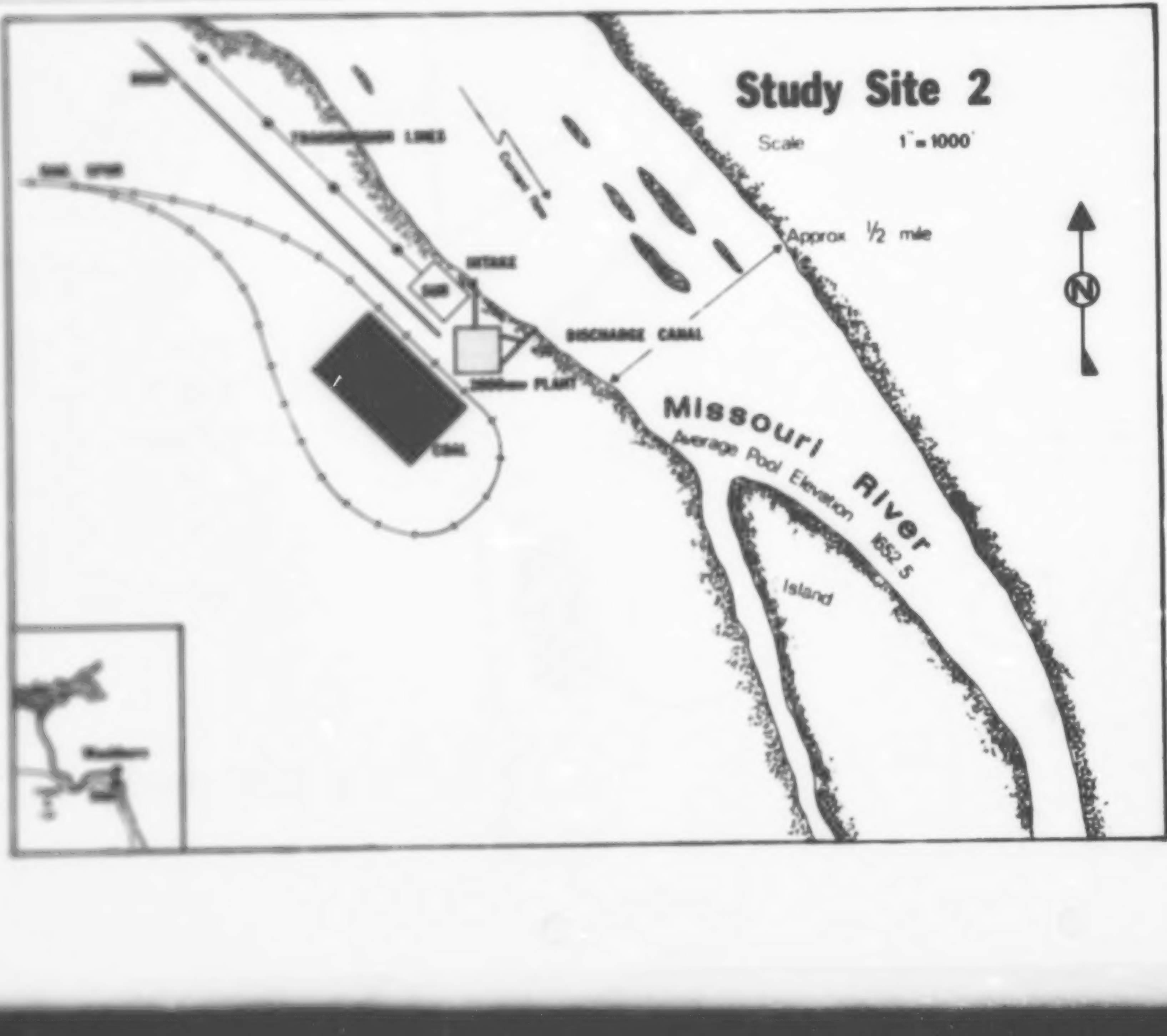
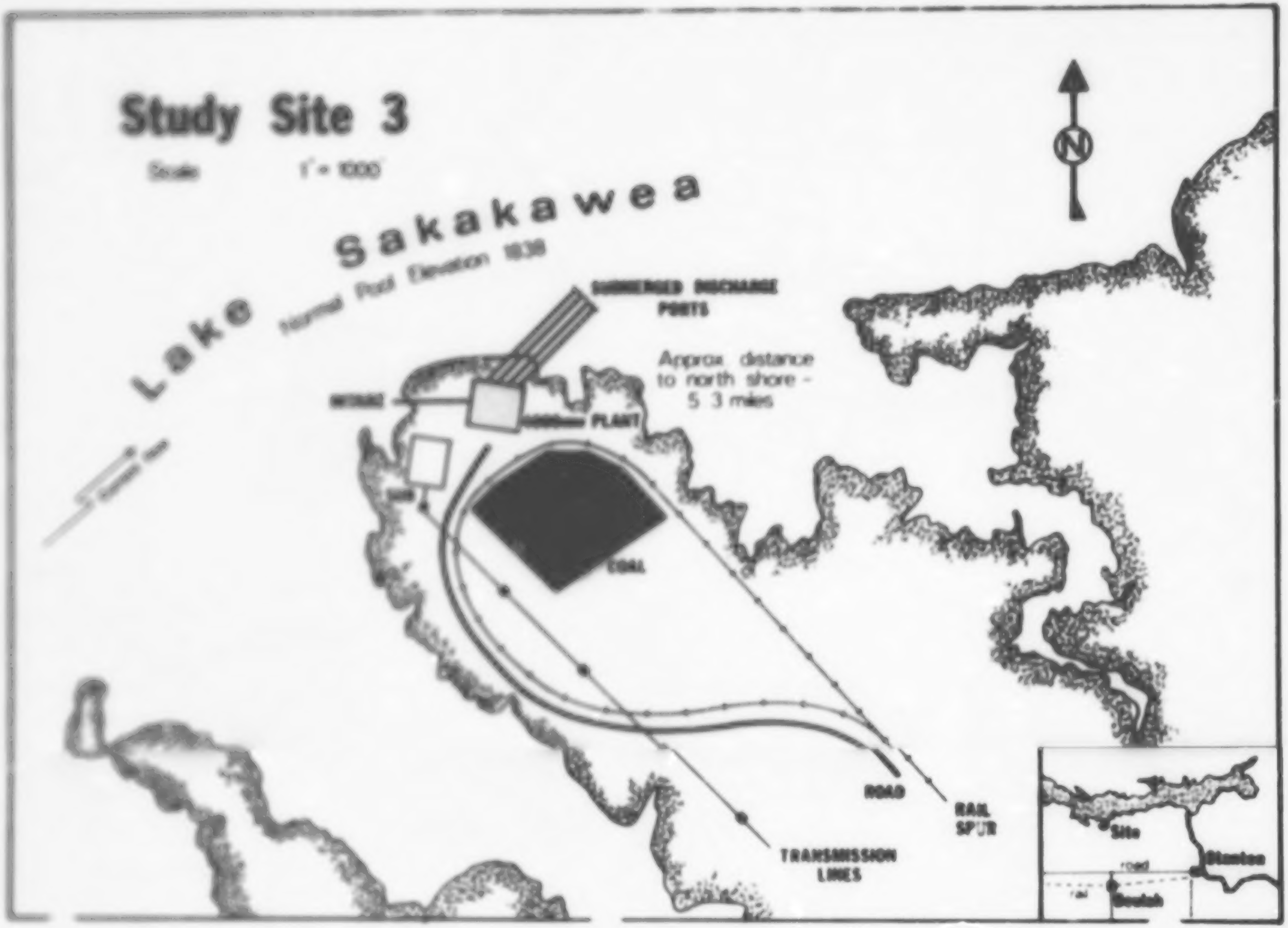

Study Site 1
Scale 1" = 1000'
N
COAL
RAIL SPUR
INTAKE
4000 mw PLANT
ROAD
SUB
TRANSMISSION LINES
Approx. 10,000' to west shore
with submerged ports 5' on center
Lake Oahe
Normal Pool Elevation 1608
Island
Ft. Yates
Dam
N. Dak.
S. Dak.

FIGURE 2


Study Site 2
Scale 1" = 1000'
Approx 1/2 mile
N
TRANSMISSION LINES
RAIL SPUR
INTAKE
DISCHARGE CANAL
PLANT
COAL
Missouri River
Average Pool Elevation 1652.5
Island



Study Site 3

Scale 1" = 1000'

Lake Sakakawea
Normal Pool Elevation 1838
SUBMERGED DISCHARGE PORTS
Approx. distance to north shore - 5.3 miles
PLANT
COAL
ROAD
RAIL SPUR
TRANSMISSION LINES
Site
road
rail
Beulah
Stanton

FIGURE 8

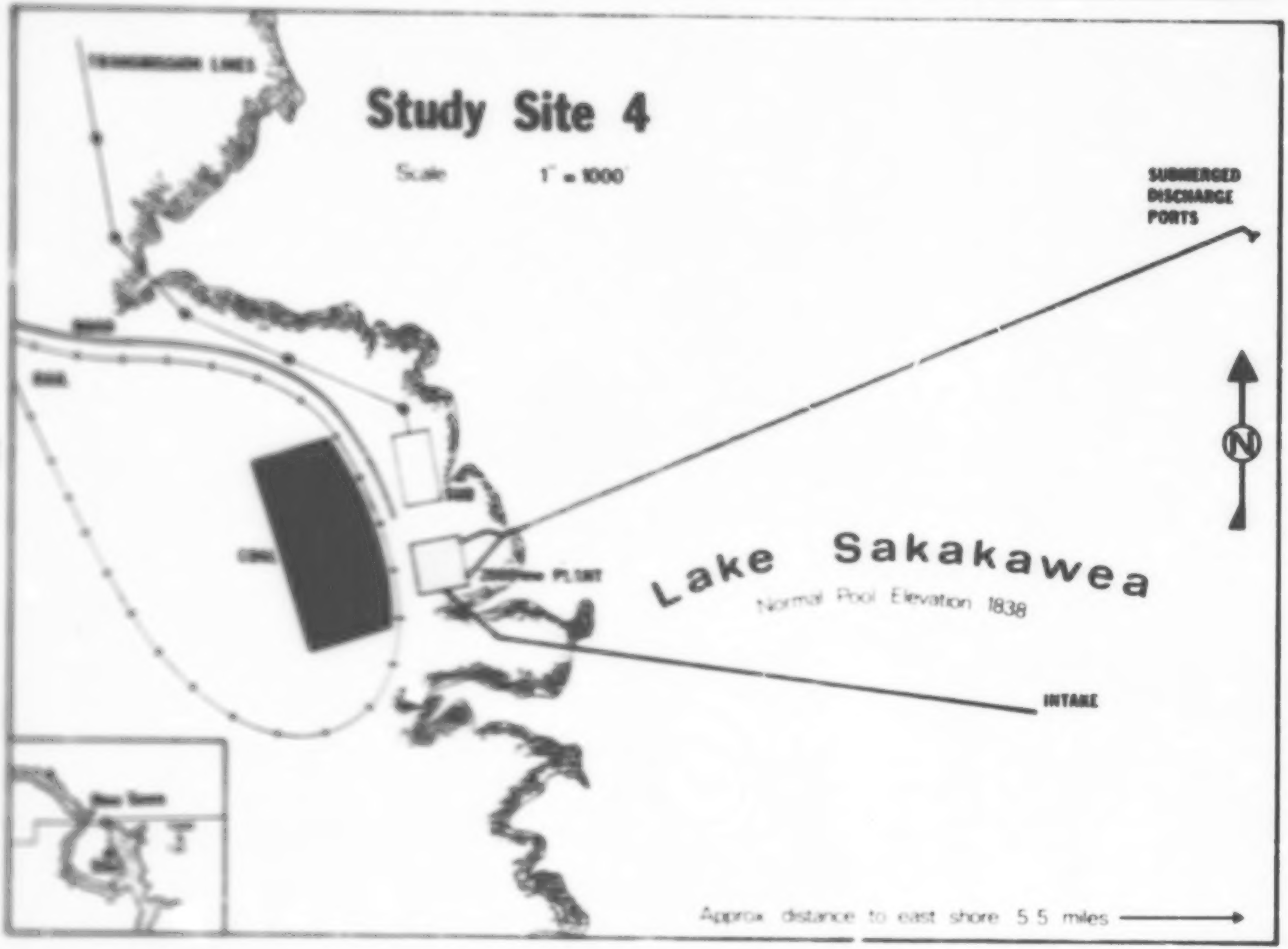

Study Site 4
Scale 1" = 1000'
TRANSMISSION LINES
SUBMERGED
DISCHARGE
PORTS
N
PLANT
Lake Sakakawea
Normal Pool Elevation 1838
INTAKE
Approx. distance to east shore 5.5 miles

FIGURE 3

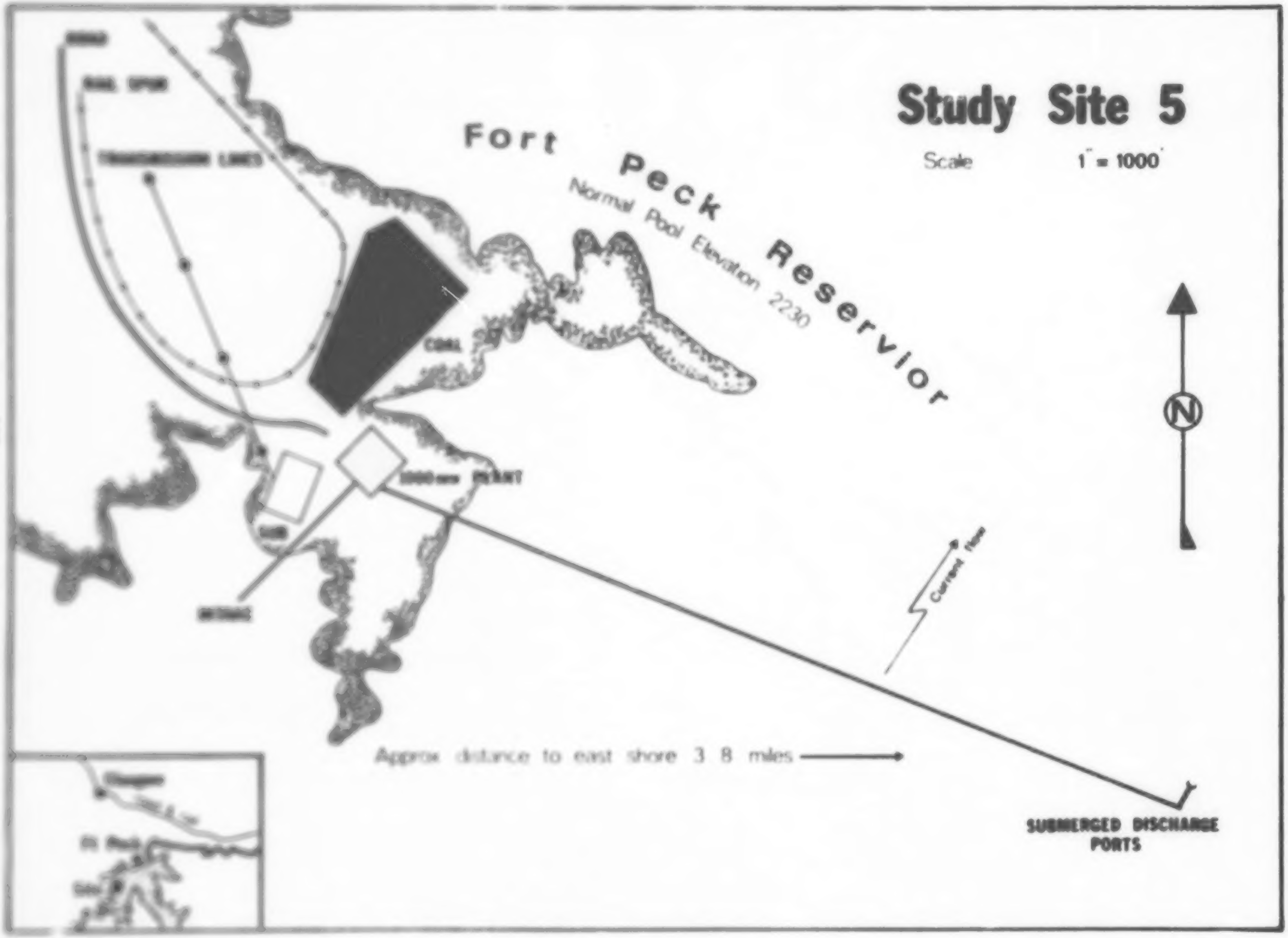
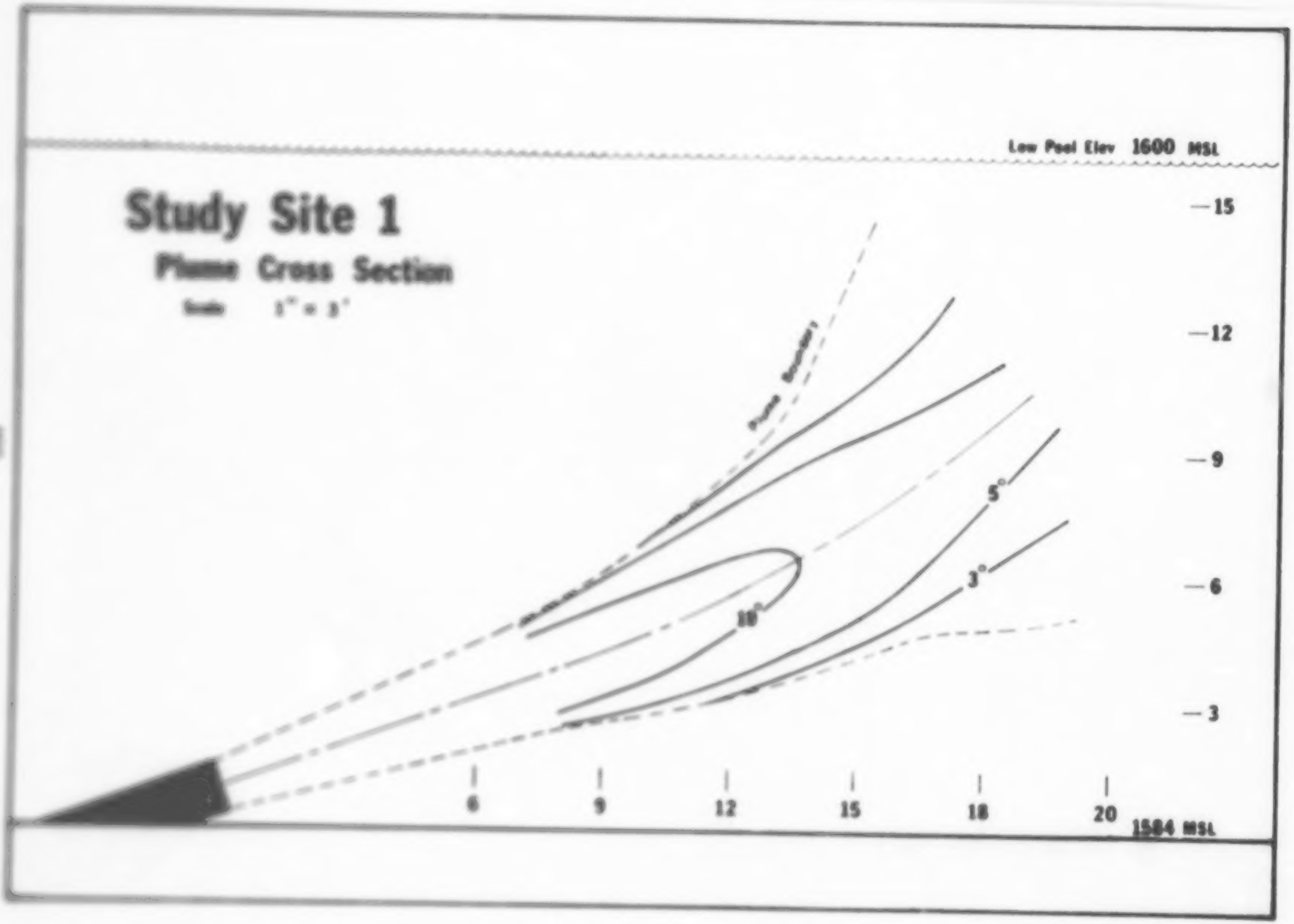

Study Site 5
Scale 1" = 1000'
Fort Peck Reservior
Normal Pool Elevation 2230
N
Current Flow
ROAD
RAIL SPUR
TRANSMISSION LINES
COAL
1000 MW PLANT
ASH
INTAKE
Approx distance to east shore 3.8 miles
SUBMERGED DISCHARGE PORTS
Ft. Peck

FIGURE 8



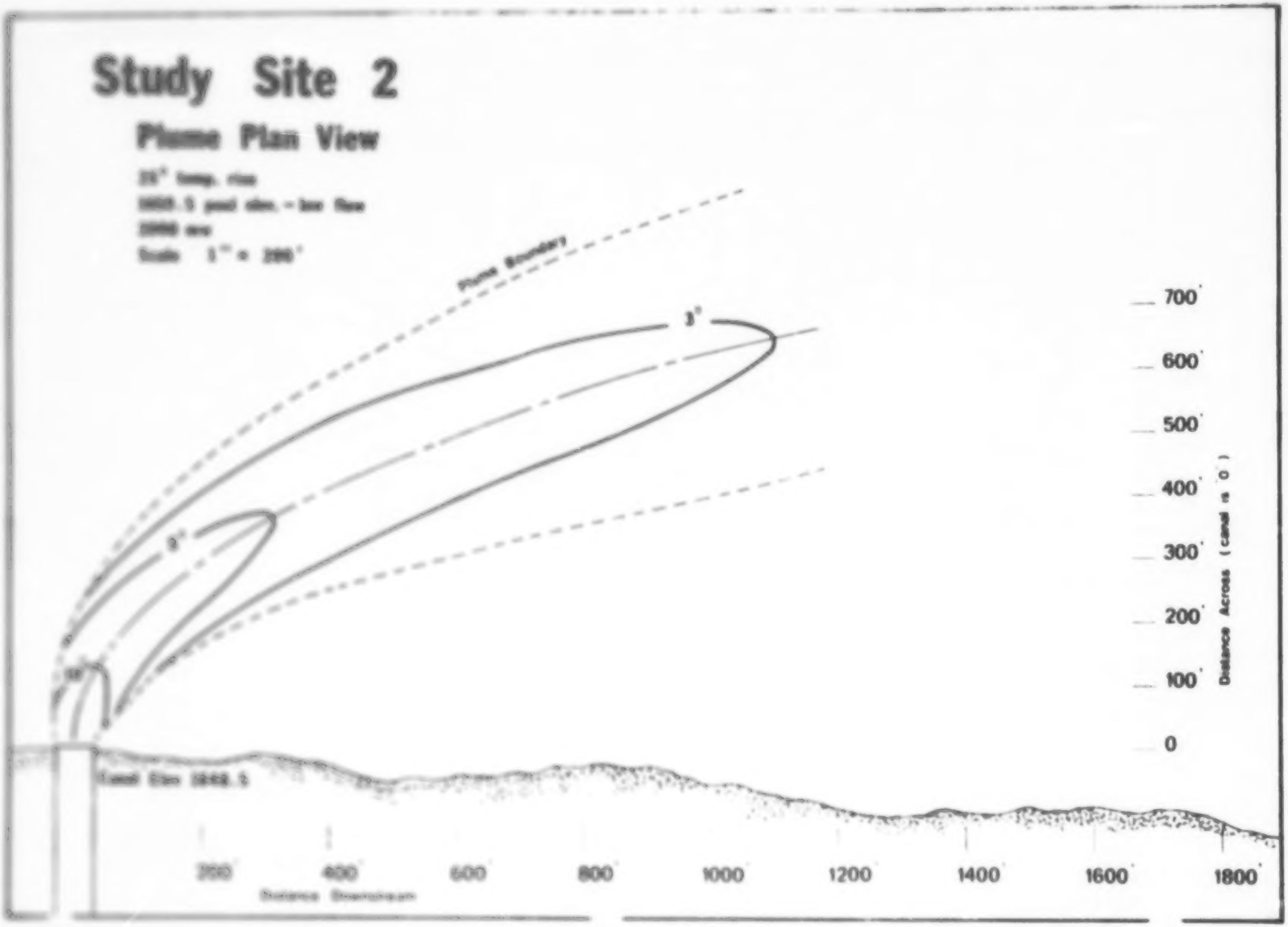
Study Site 1

Plume Cross Section

Scale 1" = 3'

Low Pool Elev 1600 MSL
Plume Boundary
10°
5°
3°
15
12
9
6
3
6
9
12
15
18
20
1584 MSL

FIGURE 7



Study Site 2

Plume Plan View

[illegible]

Scale 1" = 200'

FIGURE 8

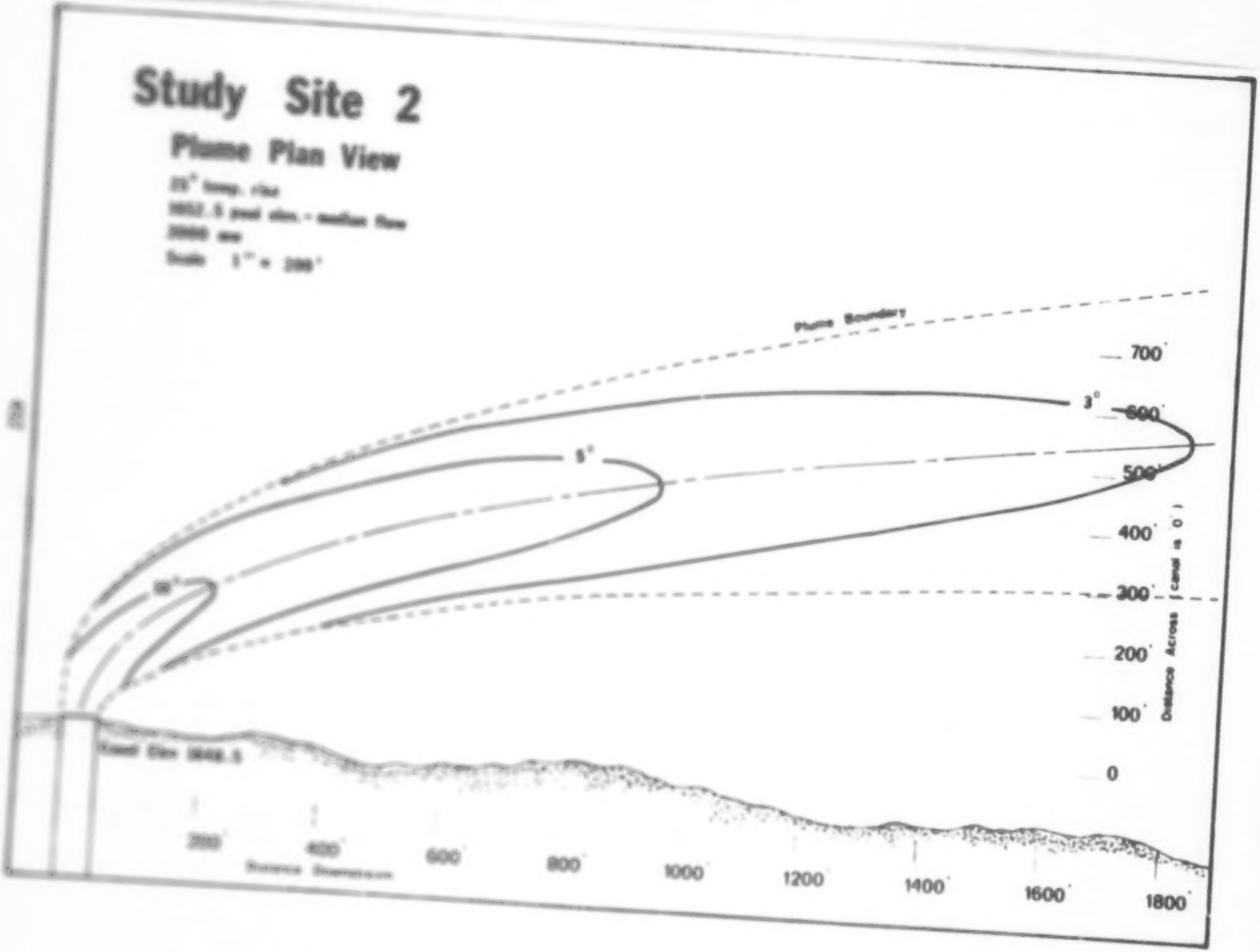

Study Site 2
Plume Plan View
Scale 1" = 200'
Plume Boundary
3°
5°
10°
700'
600'
500'
400'
300'
200'
100'
0
Distance Across (canal is 0)
200'
400'
600'
800'
1000'
1200'
1400'
1600'
1800'
Distance Downstream

FIGURE 8

Study Site 2

Plume Plan View

[illegible] temp. rise
[illegible] gpd disc. - high flow
[illegible]
Scale 1" = 200'

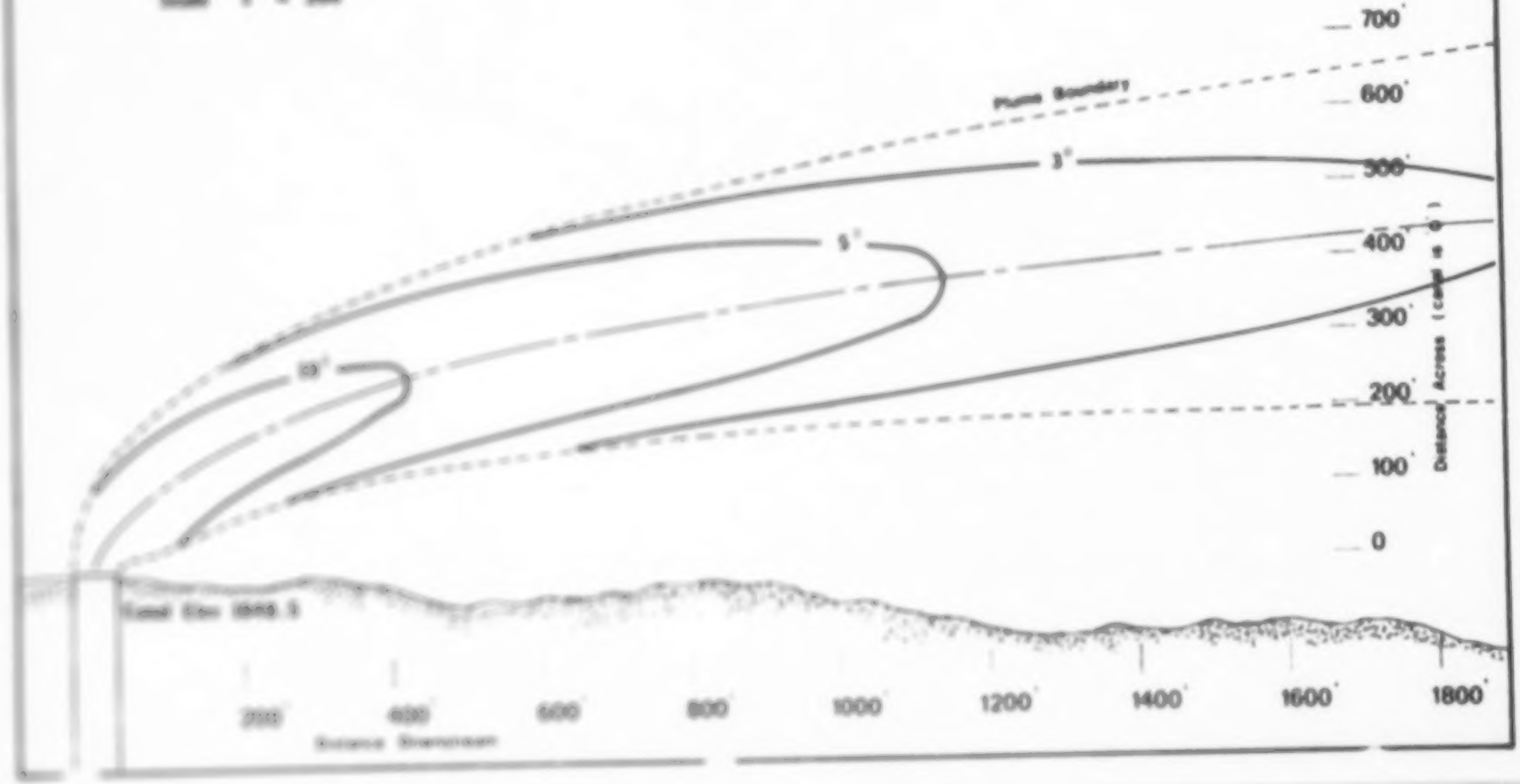
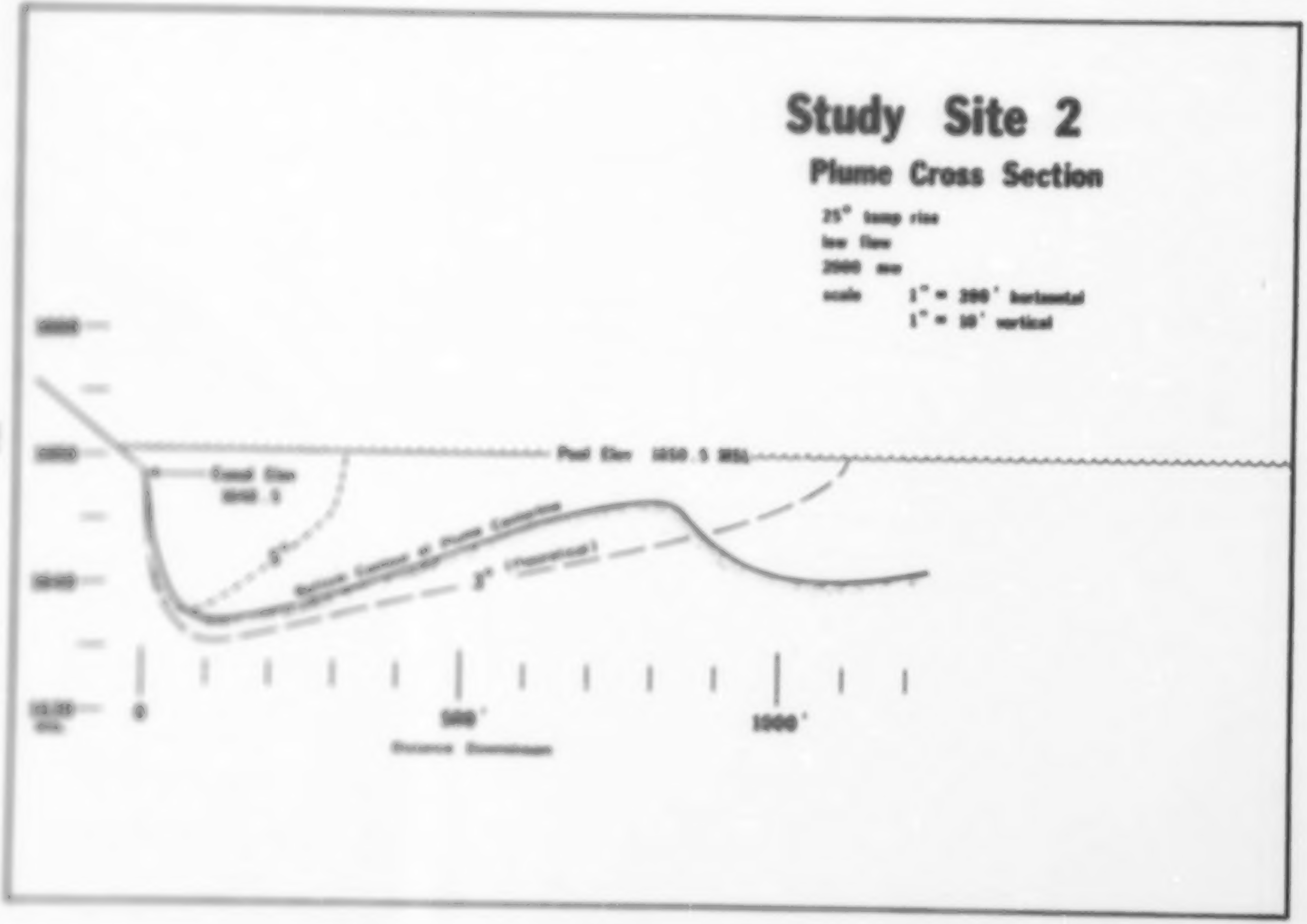


FIGURE 33



Study Site 2

Plume Cross Section

25° temp rise
low flow
2000 mw
scale 1" = 200' horizontal
1" = 10' vertical

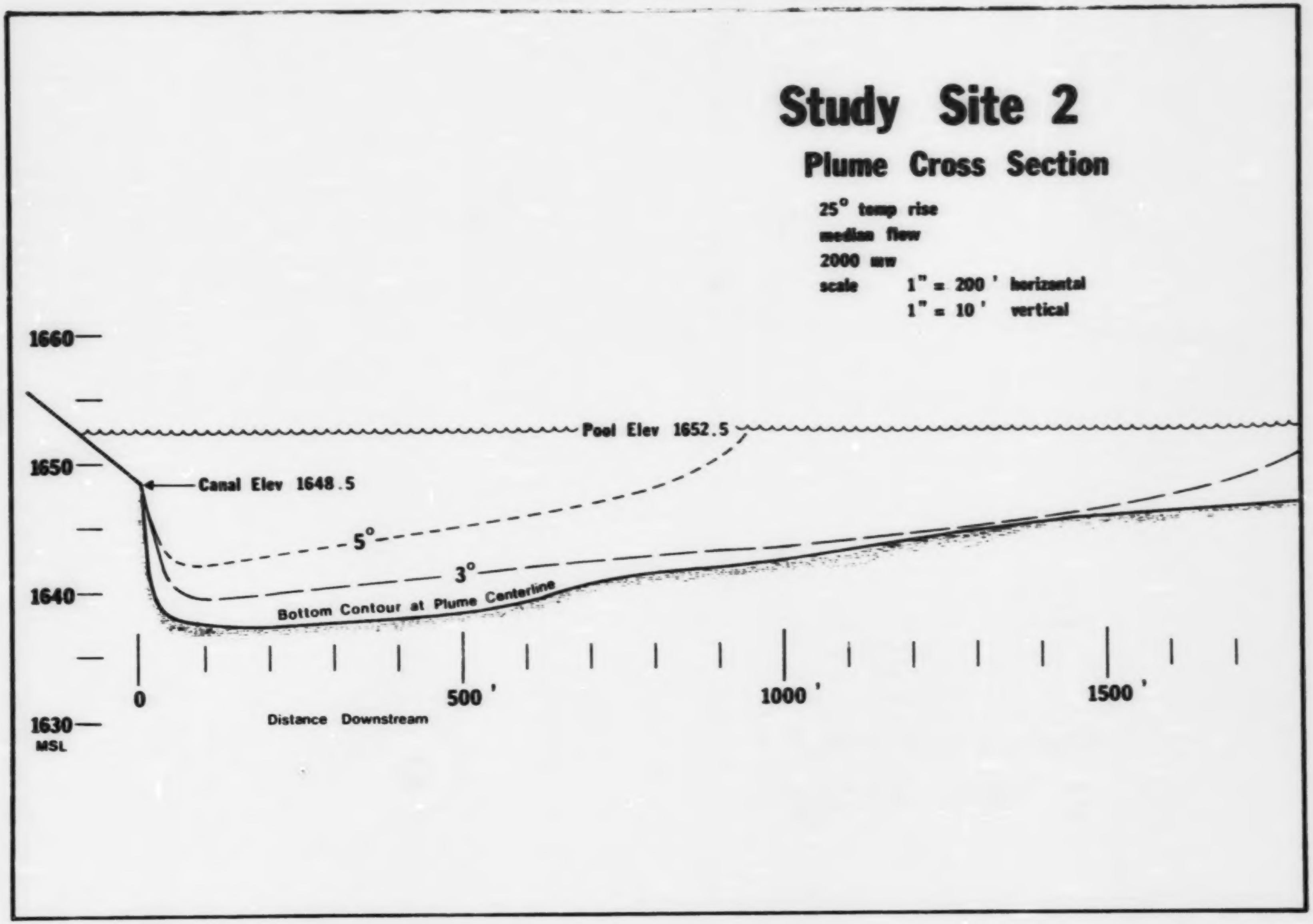
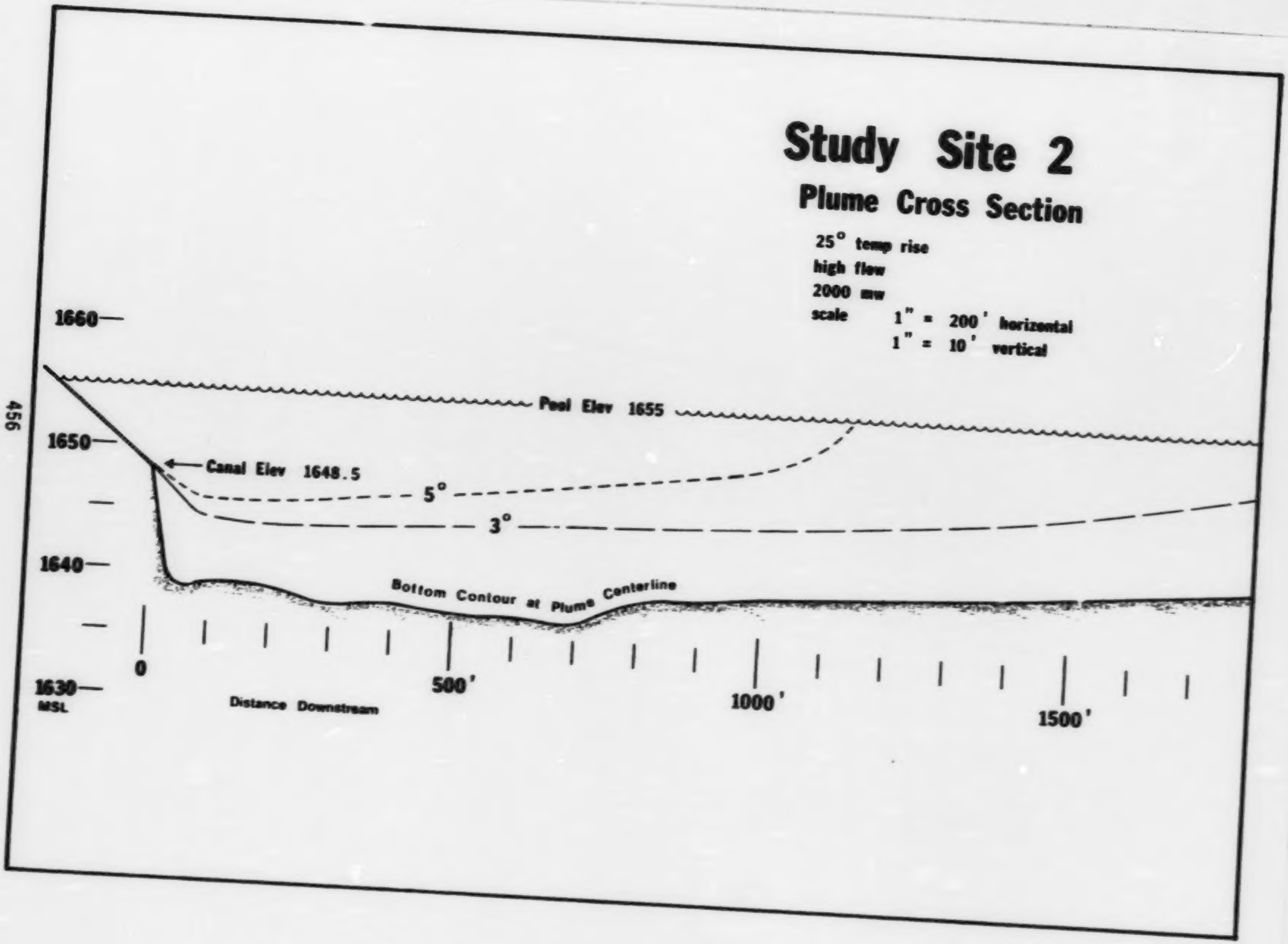

Study Site 2
Plume Cross Section
25° temp rise
median flow
2000 mw
scale 1" = 200 ' horizontal
1" = 10 ' vertical
1660
1650
1640
1630
MSL
Pool Elev 1652.5
Canal Elev 1648.5
5°
3°
Bottom Contour at Plume Centerline
0
500 '
1000 '
1500 '
Distance Downstream

FIGURE 12



Study Site 2

Plume Cross Section

25° temp rise
high flow
2000 mw
scale 1" = 200' horizontal
1" = 10' vertical

FIGURE 13

Study Site 3

Plume Plan View

Scale 1" = 30'

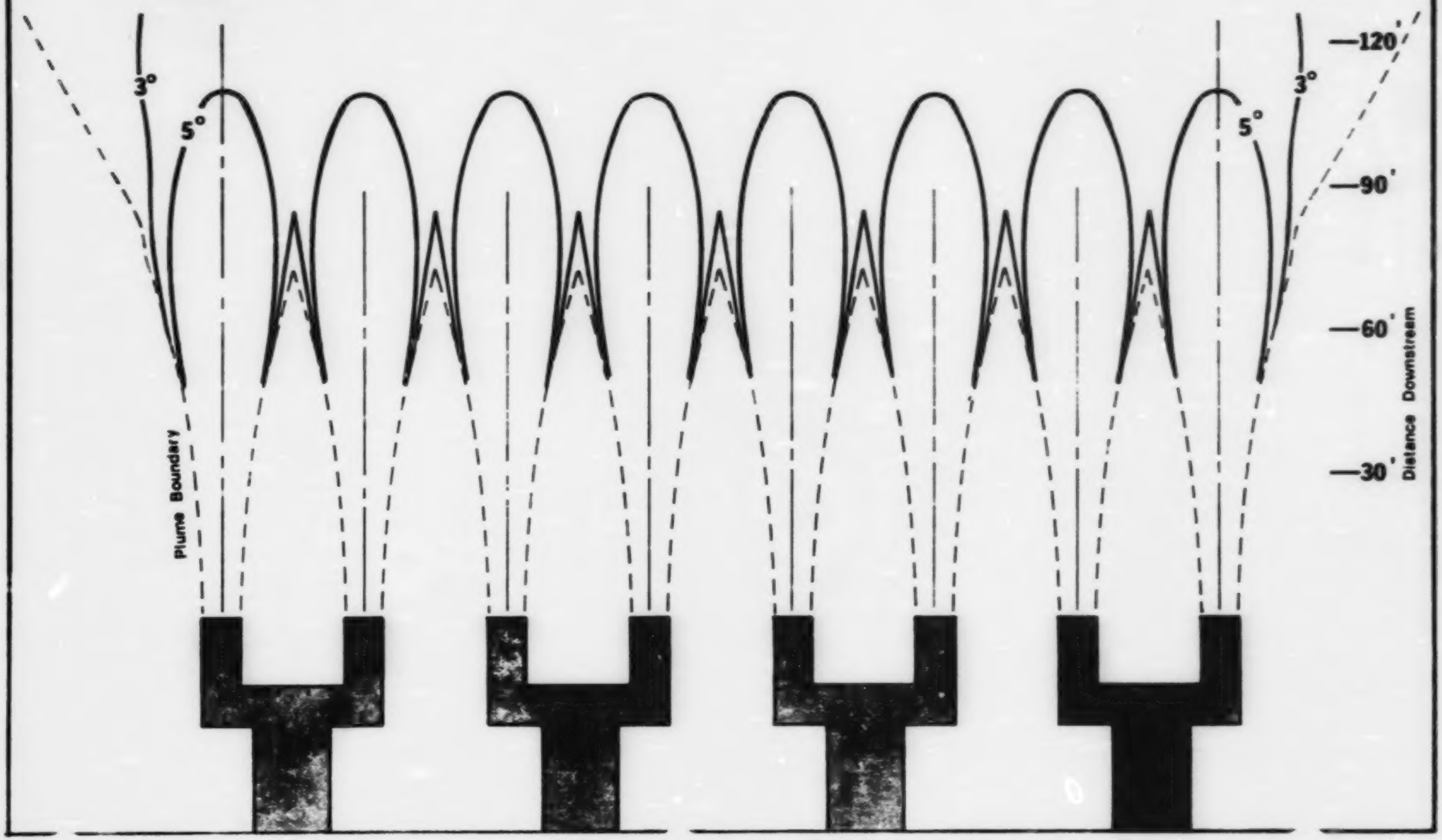
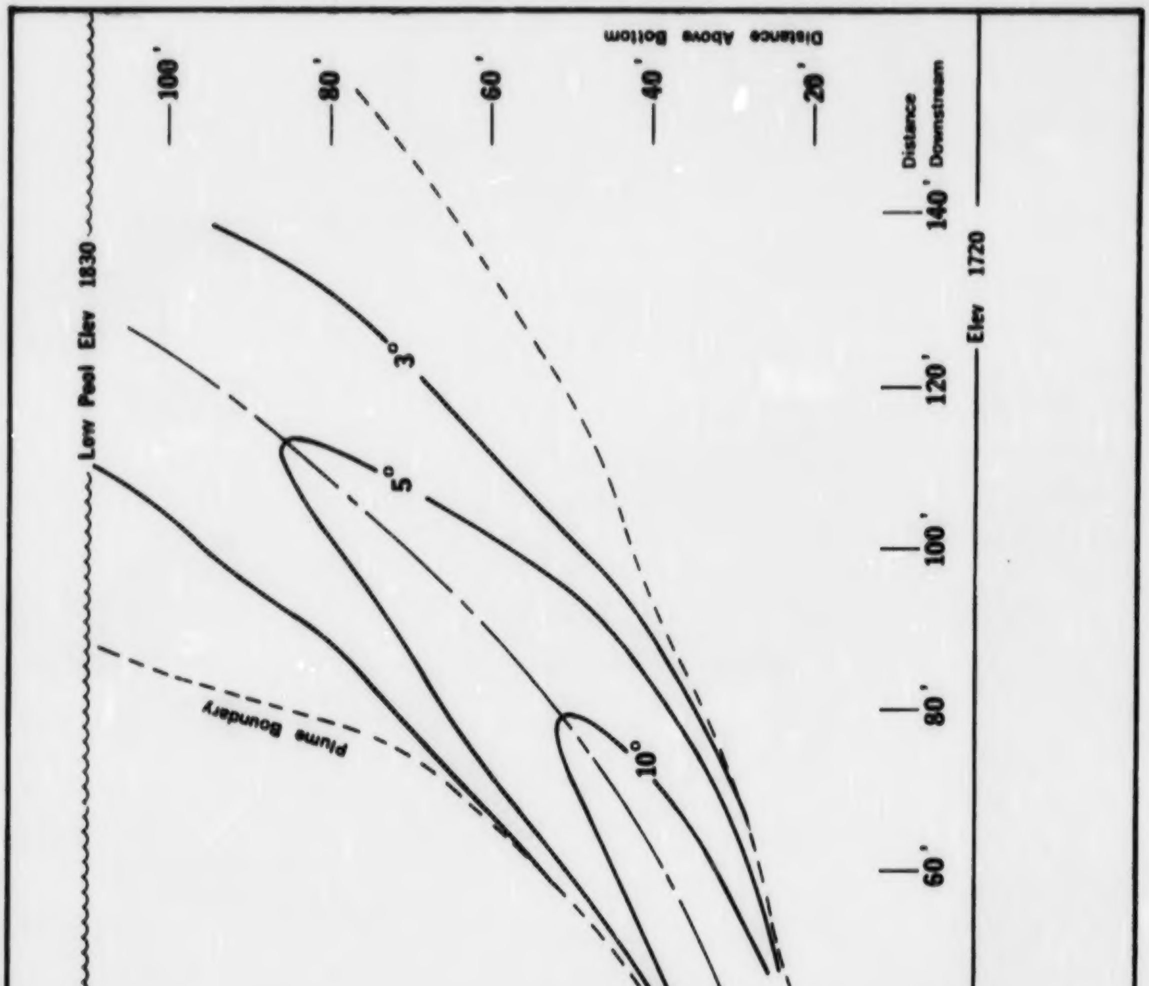

3°
5°
5°
3°
—120'
—90'
—60'
—30'
Distance Downstream
Plume Boundary

FIGURE 14



Study Site 3

Plume Cross-Section

Scale 1" = 20'

Study Site 4

Plume Plan View

Scale 1" = 30'

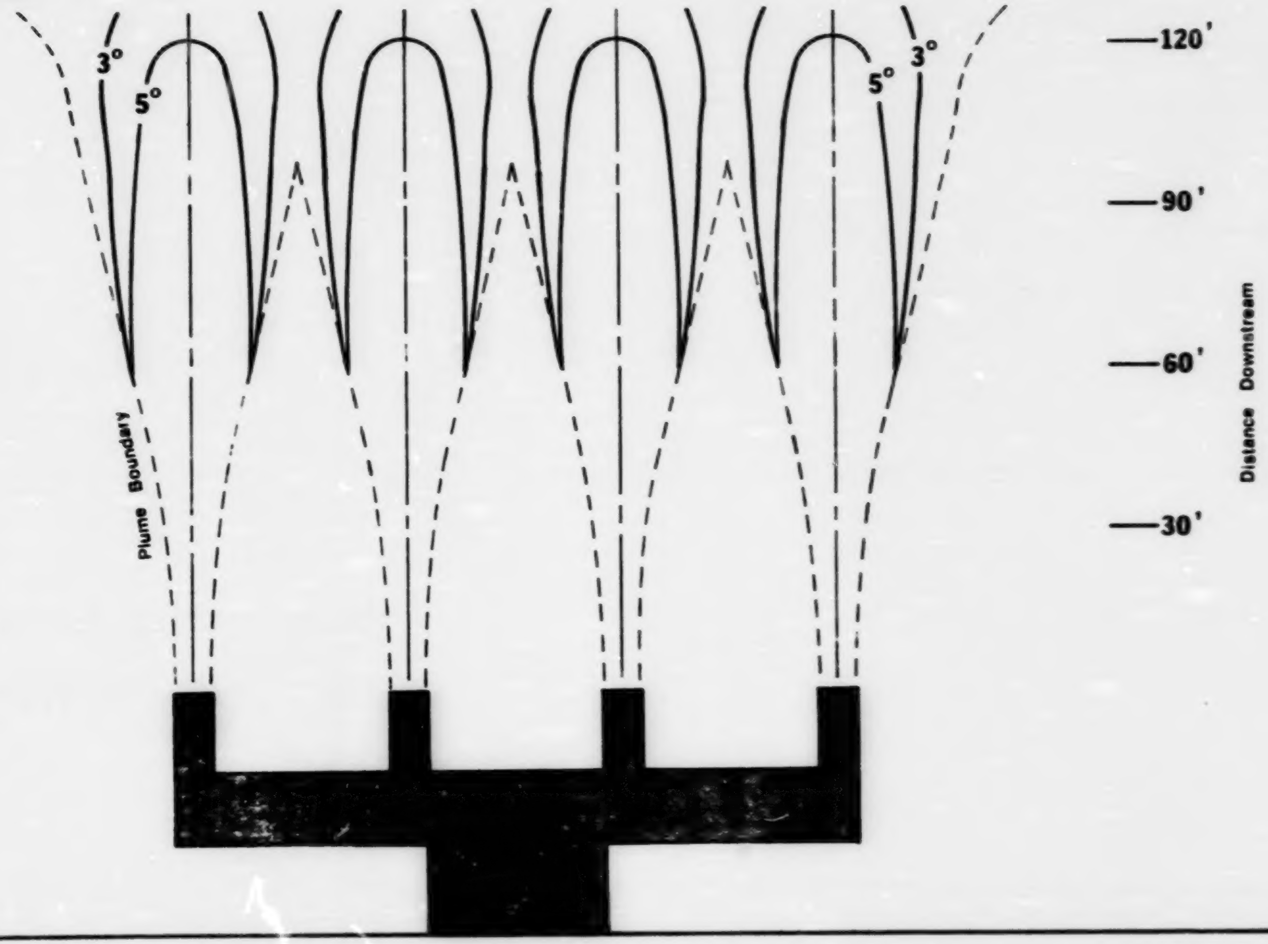

3°
5°
5°
3°
—120'
—90'
—60'
—30'
Distance Downstream
Plume Boundary

FIGURE 16

Study Site 4

Plume Cross-Section

Scale 1" = 20'

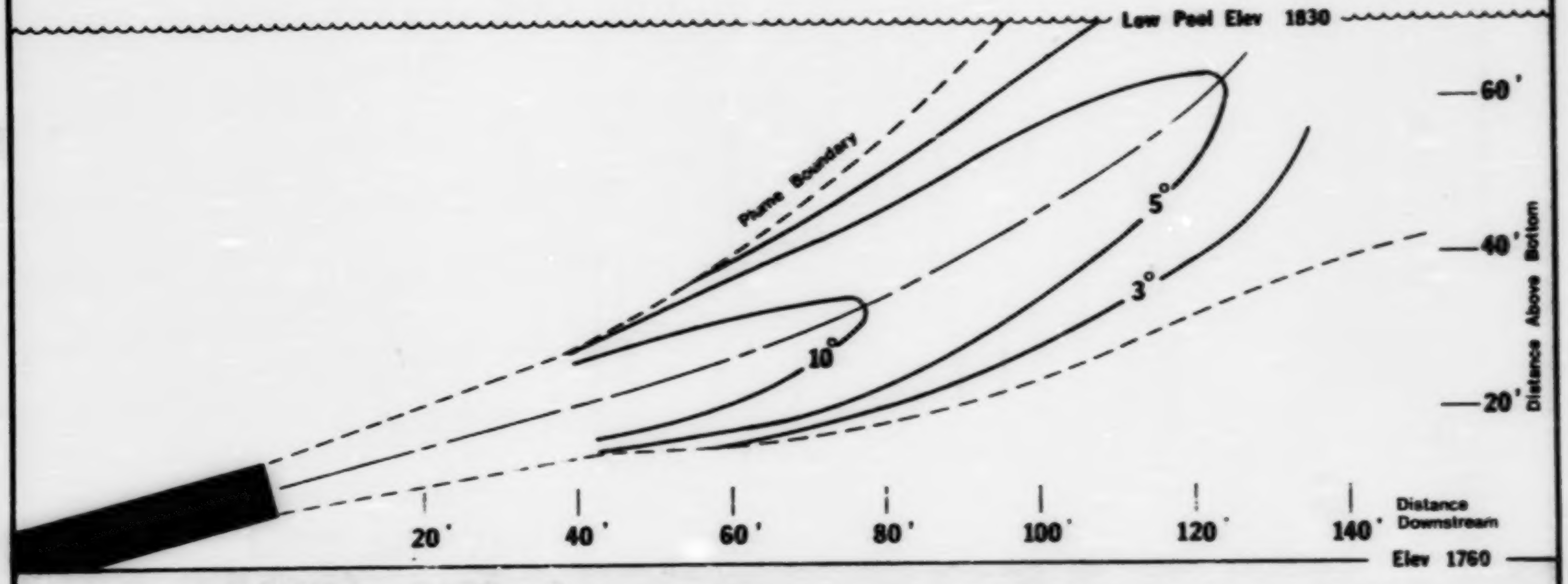


FIGURE 17

Study Site 5

Plume Plan View

Scale 1" = 30'

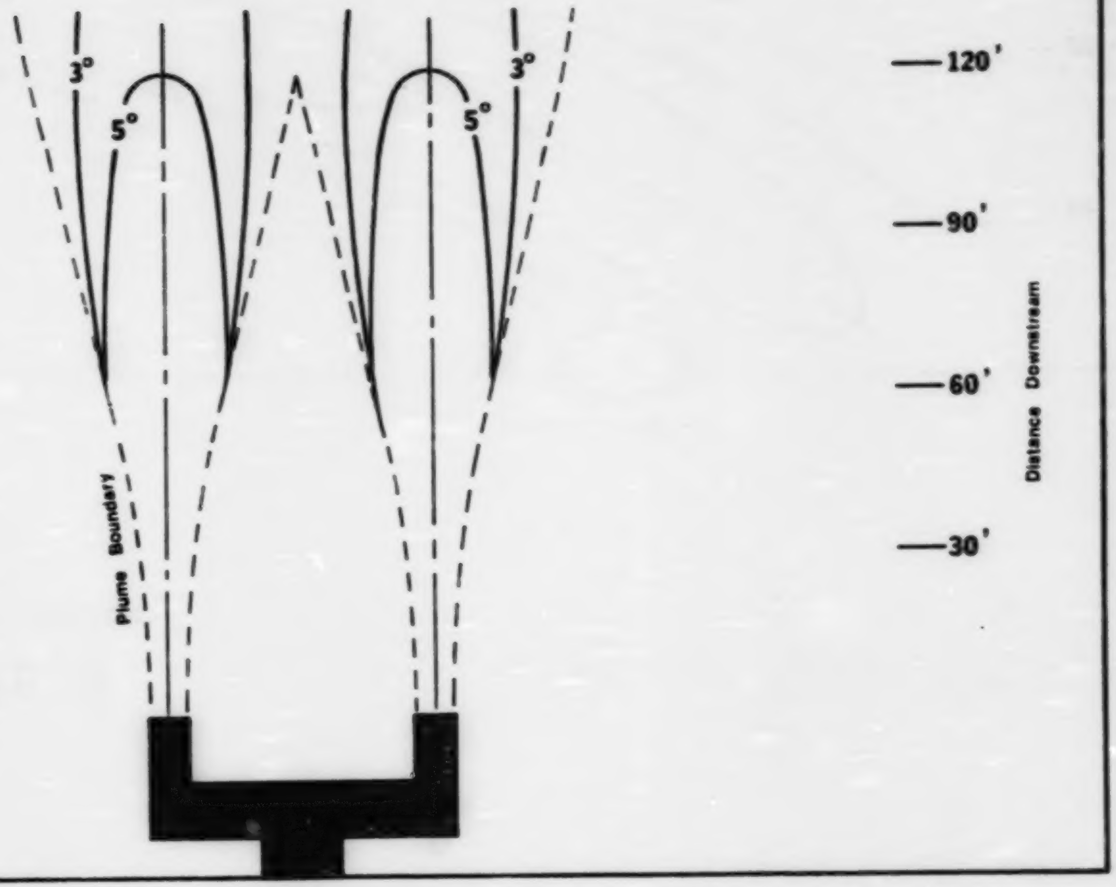

3°
5°
5°
3°
Plume Boundary
120'
90'
60'
30'
Distance Downstream

FIGURE 18

Study Site 5

Plume Cross-Section

Scale 1" = 20'

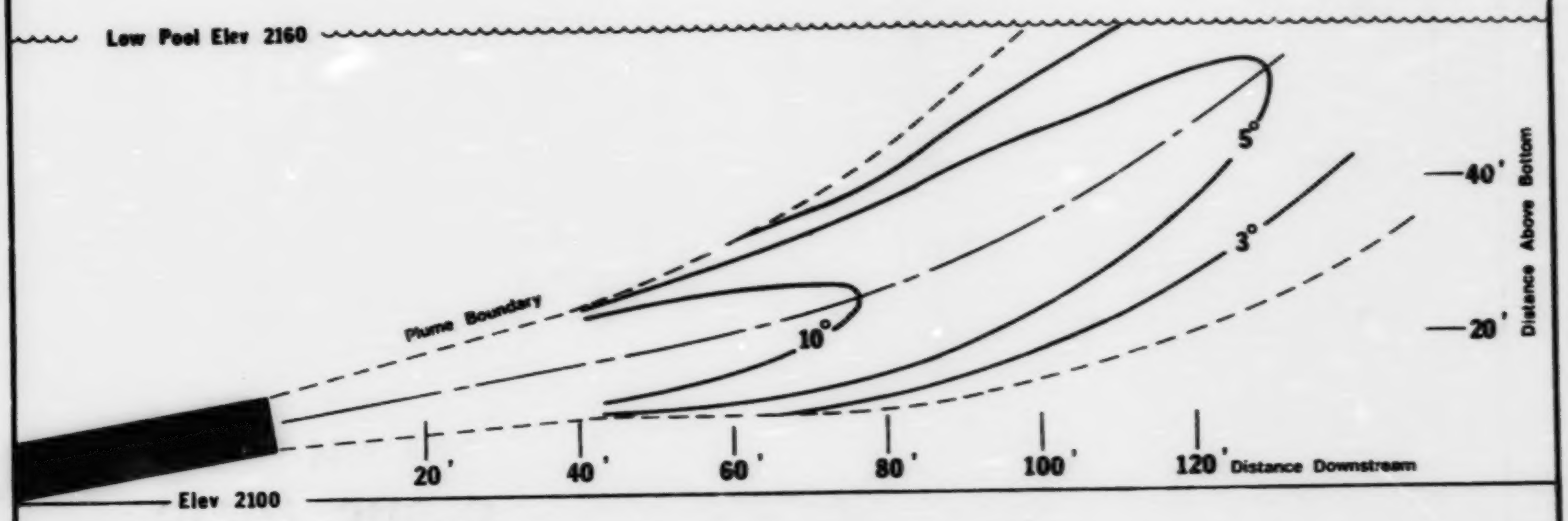

Low Pool Elev 2160
Plume Boundary
10°
5°
3°
—40'
—20'
Distance Above Bottom
20'
40'
60'
80'
100'
120' Distance Downstream
Elev 2100

FIGURE 19

Appendix A

ROW Buoyant Jet Model

```
30BUDY JET                                          JANUARY 9, 1975

30BUDY JET      FORTRAN PROG FOR BUDY.JET
```

```
                                                              ODF FILE SDBUOY JET
C  RDW BUOYANT JETS WITH IMPINGEMENT PROGRAM
C     STAGNANT ENVIRONMENT
C*****FILE NAME               : SDBUOY JET    ******************************
C*****INPUT DATA FILE         : SDBUOY JETDT  ******************************
C*****TERMINAL JOB ENTRY FILE : SDBUOY-JCL    ******************************
      DIMENSION TA(50),D(50),DENA(50),YT(50),ZD(50),VT(50),INFO(20),
     1          SEP(3),WID(3)
      REAL LAMBDR,LAMBDS,M
      COMMON LAMBDR,LAMBDS,M,ALPHAR,ALPHAS,NC,ET,D1,PAI,GRAVAC,VT,IK,ICH
     1EK,ISLOT,SPACJ,SQRDTH,CLAM2,NSTRAT,H
      COMMON Y(6),YP(6),S,DS
      DATA SEP/1.,5.0,10./
C     SEP AND THE DEGREE ISOTHERMS PRINT OUT.
    1 FORMAT(4I2,1X1,2X,3F10.5)
    5 FORMAT(I2,8X,4F10.5)
   10 FORMAT(3F10.5)
   11 FORMAT(8F10.5)
  190 FORMAT(20A4)
      SQ2=SQRT(2.)
      PAI=3.14159265
      READ(5,5)NCASE,ALPHAR,ALPHAS,LAMBDR,LAMBDS
      DO 2 MANY=1,NCASE
      READ(5,190)(INFO(I),I=1,20)
      READ(5,1,END=7)KTYPE,KK,KTH,NC,JSLOT,KSI,GRAVAC,DEVELP,STEPR
      READ(5,10) (D(I),TA(I),DENA(I),I=1,NC)
      DO 4 I=1,NC
      IF(DENA(I).LE.0.0) DENA(I)=RHOF(TA(I),GRAVAC)
    4 CONTINUE
      DO 2 KK=1,KK
      IF(KTYPE.NE.1)GO TO 6
      READ(5,11)DO,DEN1,TO,THETAO,DTHETA,DD,SPACJ,DJ
      IF(DEN1.LE.0.)DEN1=RHOF(TO,GRAVAC)
      GO TO 8
    6 READ(5,11)DO,WATTM,DELT,THETAO,DTHETA,DD,SPACJ,DJ
      QO=WATTM*4000./(1.0*62.4*DELT*3.6)
      IF(GRAVAC.GT.900.)QO=WATTM*1.E4/(1.0*DELT*3.6)
      IF(GRAVAC.LT.30.)QO=WATTM/(1.0*DELT*3.6)
      TO=TA(1)+DELT
      UO=QO*1.2732395/DO**2
      IF(JSLOT.GT.0)UO=QO/(DO*SPACJ)
      DEN1=RHOF(TO,GRAVAC)
      WRITE(6,191)(INFO(I),I=1,20)
  191 FORMAT('1',5X,20A4)
      WRITE(6,9)WATTM,UO,QO
    8 FORMAT (1HOF7.0,' MEGA WATT',5X,F5.0,'-PORT DISCH.',5X,F8.2,'VOL/SEC/
     1JET')
    9 DO 2 KY=1,KTH
      ISLOT=JSLOT
      KS=KSI
      IF(KY.GT.1)THETAO=THETAO+DTHETA
      KKFV=0
      IF(STEPR.LE.0.)STEPR=1.
```

```
                                        PAGE   2               ODF FILE SDBUOY JET
      DO 999 I=1,NC
  999 YT(I)=DJ-D(I)
      THETA=THETAO*PAI/180.
      ICH=0
      I=0
C     CHECK PHYSICAL UNITS
      IF (GRAVAC-900.) 97,97,98
   97 IF (GRAVAC-30.) 101,99,99
C     IN FPS UNITS
   99 WRITE (6,100) DO,UO,TO,DEN1,THETAO,DJ,SPACJ,D(I)
  100 FORMAT (1H1ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED ST
     1AGNANT ENVIRONMENT'///5X,'JET DIAMETER=',1PE8.2,' FEET',27X,
     2'JET DISCHARGE VELOCITY=',E8.2,'FEET/SEC'/5X,'JET DISCHARGE TEMPER
     3ATURE=',E8.2,'DEGREE FAHRENHEIT', 5X, 'JET DISCHARGE DENSITY=',F10.7,
     4'SLUGS PER FT3'/5X,'JET DISCH. ANGLE=', E8.2,' DEGREES',10X,'JET DIS
     5CHARGE DEPTH=',E8.2,'FEET'/5X,'JET SPACING C-C=',E8.2,'FEET',24X,
     6'WATER BODY DEPTH =',E8.1,'FEET')
      GO TO 110
C     IN MKS UNITS
  101 WRITE (6,102) DO,UO, TO, DEN1, THETAO,DJ, SPACJ
  102 FORMAT (1H1ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED
     1STAGNANT ENVIRONMENT///5X, 15HJET DIAMETER=,1PE8.2,6HMETERS,9X,
     223HJET DISCHARGE VELOCITY=,1PE8.2,8HMET./SEC/5X, 26HJET DISCHARGE T
     3EMPERATURE=,1PE8.2,15HDEGREE CENTIG, 5X, 22HJET DISCHARGE DENSITY=,
     41PE10.7, 11HGRAM PER ML/5X,19H JET DISCH. ANGLE=, 1PE8.2,8H DEGREES/
     55X,20HJET DISCHARGE DEPTH=,1PE8.2,6HMETERS, 5X,16HJET SPACING C-C=,
     61PE8.2,6HMETERS)
      GO TO 110
C     IN CGS UNITS
   98 WRITE (6,103) DO,UO, TO, DEN1, THETAO,DJ, SPACJ
  103 FORMAT (1H1ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED
     1STAGNANT ENVIRONMENT///5X, 15HJET DIAMETER=,1PE8.2,4H CM.,9X,
     223HJET DISCHARGE VELOCITY=,1PE8.2,8H CM./SEC/5X, 26HJET DISCHARGE T
     3EMPERATURE=,1PE8.2,13HDEGREE CENTIG, 5X, 22HJET DISCHARGE DENSITY=,
     41PE10.7, 11HGRAM PER ML/5X,19H JET DISCH. ANGLE=, 1PE8.2,8H DEGREES/
     55X,20HJET DISCHARGE DEPTH=,1PE8.2,4H CM.,   5X,16HJET SPACING C-C=,
     61PE8.2,4H CM.)
C 129 FORMAT(/5X,' H/HO=',F10.4,10X,' FS=',F10.4)
  111 FORMAT(/'     X         Y        WIDTH  DILUTION     U     DELTA-TEMP
     1     S    LOCAL FRD   ANGLE    50.WIDTH  90.WIDTH  130.WIDTH'/)
  110 S=0.
C     TO FIND REFERENCE TEMPERATURE AND DENSITY
      IR=1
      IF (DJ-D(IR))  112,113,114
  113 TR=TA(IR)
      DENR=DENA(IR)
      IF(ISLOT)118,118,218
  112 IR=IR+1
      IF (DJ-D(IR)) 112,113,117
  114 WRITE (6,120)
  120 FORMAT(5X,55H INSUFFICIENT DATA ON AMBIENT DENSITY AND TEMPERATURE
     1)
```

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```
      KR=KK
      KV=KTH
      GO TO 2
  117 SL=(DJ-D(IR))/(D(IR-1)-D(IR))
      TR=TA(IR)+SL*(TA(IR-1)-TA(IR))
      DENR=DENA(IR)+SL*(DENA(IR-1)-DENA(IR))
      IF(ISLOT.GT.0) GO TO 218
C     INITIAL CONDITIONS
  118 V(1)=PAI*DO*DO*UO*0.5
      M=V(1)*UO*0.5
      V(3)=V(1)*(DENR-DENJ)/DENR*0.5
      V(4)=V(1)*(TR-TO)/TR*0.5
      GO TO 219
  218 WRITE(6,230)
  230 FORMAT(10X'THIS IS A 2-DIMENSIONAL SLOT JET--SLOT WIDTH=JET DIAMET
     1ER, SLOT LENGTH=JET SPACING',/)
      V(1)=SQ2*UO*DO*SPACJ
      M=V(1)*UO/SQ2
      V(3)=V(1)*(DENR-DENJ)/(DENR*SQ2)
      V(4)=V(1)*(TR-TO)/(TR*SQ2)
  219 WRITE(6,111)
      VOLFJ=V(1)
      V(2)=M*SIN(THETA)
      V(5)=DEVELP*DO*COS(THETA)
      V(6)=DEVELP*DO*SIN(THETA)
      H=M*COS(THETA)
      IP=3
      IQ=2
      IF(ISLOT.LE.0)SQLAM=(1.+LAMBDR*LAMBDR)/(LAMBDR*LAMBDR)
      IF(ISLOT.GE.0)SQRLAM=SQRT(1.+LAMBDS*LAMBDS)/LAMBDS
C     CALCULATION OF DENSITY AND TEMPERATURE GRADIENTS
      NC1=NC-1
      DO 912 I=1,NC1
      I1=I+1
      DP1=VT(I1)-VT(I)
      ET(I)=(TA(I1)-TA(I))/(TR*DP1)
  912 ED(I)=(DENA(I1)-DENA(I))/(DENR*DP1)
      NSTRAT=0
      IF(NC1.GT.1.OR.ABS(ED).GT.1.E-10.OR.ABS(ET).GT.1.E-8)GO TO 913
      NSTRAT=1
      VP(5)=0.
      VP(6)=3.
  913 SJP=DO*2.
      PI=3.
C     CHOICE OF INTEGRATION STEP
      DS1=DJ/20.
      DS2=DJ/2000.
      DS=DS1
      IF(DS1.GT.DS2)DS=DS2
      DS=DS/STEPDI
C     INTEGRATION BY RUNGE-KUTTA METHOD
      IF(ISLOT.EQ.0)TRANW=2.*ALPHAS*SPACJ/(PAI*ALPHAR)
```

```
      CALL DERIV(V)
  304 V2O=V(2)
      CALL RUNGS
C
C  CHECKING FOR HITTING SURFACE
C
      IF(V(6).LT.DJ)GO TO 305
      WRITE (6,532)
  532 FORMAT (13X,23HTHIS IS FREE SURFACE,/)
      GO TO 12
  305 ANGLE=ATAN(V(2)/H)*57.2957795
C
C  CHECK FOR REVERSAL OF MOMENTUM
C
      IF(V2O*V(2).GE.0.)GO TO 306
      KREV=KREV+1
      IF(KREV.LE.2)GO TO 306
      WRITE(6,533)
  533 FORMAT(10X,'THREE REVERSALS OF MOMENTUM - END OF RUN',///)
      GO TO 2
  306 IF(ISLOT.GT.0)GO TO 310
      M=SQRT(H*H+V(2)**2)
      WIDTH=2.*V(1)/SQRT(PAI*M)
      IF(ISLOT.LT.0)GO TO 301
      IF(WIDTH.GE.TRANW)GO TO 206
C
C  SHOULD WE PRINT
C
  301 IF(S.LT.PI) GO TO 304
      DENDIF=SQLAM*DENR*V(3)/V(1)
      TDIF=SQLAM*TR*V(4)/V(1)
      DILU=V(1)/VOLFJ
      IF(DENDIF.GE.0.)GO TO 906
      DENDIF=DENDIF*0.5
      TDIF=0.5*TDIF
      GO TO 906
  206 ISLOT=1
      WRITE (6,1222)
 1222 FORMAT (10X, 20HTRANSITION POINT TWO)
  310 IF(KS.LE.-1 .AND. S.LT.PI) GO TO 304
      M=SQRT(H*H+V(2)**2)
      WIDTH=V(1)**2/(SQRT(PAI)*M*SPACJ)*2.
      DENDIF=SQRLAM*DENR*V(3)/V(1)
      TDIF=SQRLAM*TR*V(4)/V(1)
      DILU=V(1)/VOLFJ
      IF(DENDIF.GE.0.)GO TO 906
      CONST=0.5*SQRT(PAI*0.5)
      DENDIF=CONST*DENDIF
      TDIF=CONST*TDIF
C  TO FIND AMBIENT DENSITY AND TEMPERATURE VALUES
  906 IY=2
  920 IF (V(6)-VT(IY))  900,901,902
  901 DENAA=DENA(IV)
      TAA=TA(IV)
      IV=IV+1
      GO TO 909
  900 IV=IV-1
      IF(IV.GT.0)GO TO 904
      WRITE(6,907)
  907 FORMAT(' PLUME FALLS BELOW LOWEST DENSITY INFORMATION - END OF RUN
     * ',///)
      GO TO 2
  904 IF (Y(6)-YT(IV)) 900,901,905
  905 IYY=IV+1
      SYY=(Y(6)-YT(IYY))/(YT(IV)-YT(IYY))
      TAA=SYY*(TA(IV)-TA(IYY))+TA(IYY)
      DENAA=SYY*(DENA(IV)-DENA(IYY))+DENA(IYY)
      GO TO 909
  902 IV=IV+1
      GO TO 920
C
C PRINTOUT
C
  909 TJ=TAA-TDIF
      DENJ=DENAA-DENDIF
      TDIFM=-TDIF
      SS=SOURVEL*DO
      FOLOC=SQRDTM*CLAM2/YP(2)/WIDTH
      IF(S.LT.PI) GO TO 700
  703 DO 908 I=1,3
      IF(TDIFM.LE.SKP(I)) GO TO 903
      WID(I)=WIDTH*SQRT(ALOG(TDIFM/SKP(I))/2.)
      IF(ISLOT.GT.0)WID(I)=WID(I)*LAMBDS
      IF(ISLOT.LE.0)WID(I)=WID(I)*LAMBDR
      GO TO 908
  903 WID(I)=0.
  908 CONTINUE
      WRITE (6,222) Y(5), Y(6),WIDTH,DILU,Y(1),TDIFM,SS,FOLOC,ANGLE
     1,(WID(I),I=1,3)
        IP=IP+1
        PI=IP*SJP
  222 FORMAT(4F9.3,F9.1,F12.7,F9.3,2F9.2,3F10.3)
C  THE FOLLOWING PART OF THIS PROGRAM IS BASED ON THE WORK OF JIRKA & HARLEMAN.
C  WE ASSUMED THAT THE FLOW IN THE PLUME IS THE SAME AS THE FLOW AFTER THE
C  IMPINGEMENT AND AFTER THE HYDRAULIC JUMP IF THE HYDRAULIC JUMP DOES HAPPEN.
C  THE COEFFICIENT K (CKL HERE) IS ASSUMED 0.2 .
      IF(KS.EQ.3)GO TO 12
  700 IF( ISLOT.LE.0 .OR. KS.LE.-1)GO TO 306
      CKL=0.2
      HA=DJ-Y(6)+WIDTH*COS(ANGLE/57.2957795)*SQRT(PAI*3.)/(8.*(1.-CKL))
      HB=DJ-Y(6)-WIDTH*COS(ANGLE/57.2957795)*SQRT(PAI*3.)/(8.*(1.-CKL))
      IF(HB.LE.0.001 .OR. HA.LE.0.001 ) KS=2
      A1=(1.-CKL)*(Y(1)/H)**2*2./SQRT(3.)
      A2=DENDIF/DENAA*GRAVAC
```

```
      UA=SQRT(A1+A2*HB*SQRLAM)
      UB=SQRT(A1+A2*HA*SQRLAM)
      IF(HB.LE.0.001) UB=0.
      IF(HB.LE.0.001)UA=Y(1)/(HA*SPACJ)
      IF(HA.LE.0.001) UA=0.
      IF(HA.LE.0.001) UB=Y(1)/(HB*SPACJ)
      QI=(UA*HA+UB*HB)*SPACJ
      DQ1=QI-Y(1)
      IF(KS.LE.0)GO TO 701
      IF(DQ1*DQ2.LE.0.001 .OR. KS.EQ.2) GO TO 702
  701 KS=1
      DQ2=DQ1
      GO TO 306
 702  IF(ISLOT.EQ.0)DILUT=DILU*2.
      IF(ISLOT.GE.1)DILUT=DILU*SQ2
      QA=(DILUT-1.)*Y(1)/(DILUT*(1.+SQRT((D(1)-HB)/(D(1)-HA))))
      QB=(DILUT-1.)*Y(1)/(DILUT*(1.+SQRT((D(1)-HA)/(D(1)-HB))))
      DENOM=SQRT(A2*D(1)**3)
      FHA1=UA*HA/DENOM
      FHA2=QA/SPACJ/DENOM
      FHB1=UB*HB/DENOM
      FHB2=QB/SPACJ/DENOM
      WRITE(6,704)HA,UA,QA,FHA1,FHA2,HB,UB,QB,FHB1,FHB2
  704 FORMAT (' POINT OF IMPINGEMENT :DOWNSTREAM : H1=',F6.2,'  U1=',F5.
     12,'  Q2=',F7.1,'  FH1=',F5.2,'  FH2=',F5.2,' 1'/25X,'UPSTREAM : H1
     2=',F5.2,'  U1=',F5.2,'  Q2=',F7.1,'  FH1=',F5.2,'  FH2=',F5.2,' 1'
     3)
      IF(KS.EQ.2)WRITE(6,708)
  708 FORMAT(' NOTE: THE VALUES OF H1,UP,Q2 AND FH2 ARE NOT NECESSARILY
     1CORRECT BECAUSE IN THIS APPROXIMATE ANALYSIS THE VALUE WE NEED IS
     2FH1.')
      KS=3
      IP=IP-1
      GO TO 703
   12 IF(KS.LE.1 .OR. ISLOT.LE.0) GO TO 2
      IF(FHA1.GE.1.) GO TO 707
      IF(FHA2.GE.1.) GO TO 707
      IF(FHB1.GE.1.) GO TO 707
      IF(FHB2.GE.1.) GO TO 707
      FHA=(FHA2+FHA1)*0.5
      FHB=(FHB1+FHB2)*0.5
      IF(FHA.LT.FHB)FHA=FHB
      FH=FHA
      IF(FH.GT.1.)WRITE(6,20)FH
   20 FORMAT(5X,'FULL MIXING EXPECTED BASED ON JIRKA & HARLEMAN. FH=',
     1 F6.2,////)
      IF(FH.LT.0.2)WRITE(6,21)FH
   21 FORMAT(5X,'STABLE STRATIFIED SURFACE PLUME EXPECTED BASED ON JIRKA
     1 & HARLEMAN. FH=',F5.3,////)
      IF(FH.GE.0.2 .AND. FH.LE.1.0) WRITE(6,22) FH
   22 FORMAT(5X,'STAGNANT WEDGE OR COUNTER FLOW SYSTEM IS EXPECTED IN TH
     1E FLOW AWAY REGION BASED ON JIRKA AND HARLEMAN. FH= ',F5.3///)
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```
      GO TO 2
  707 WRITE (6,23)
   23 FORMAT(5X,*FULL MIXING IS THE MOST POSSIBLE FLOW TYPE IN THE FLOW
     1 AWAY ZONE*///)
    2 CONTINUE
    7 STOP
      END
      FUNCTION RHOP(X,G)
      IF(G.GT.900.)GO TO 1
      IF(G.LT.33.)GO TO 1
      T=(X-32.)*5./9.
      GO TO 2
    1 T=X
    2 RHOP=1.-(T**2*6.-T*36.+47.)*0.000001
      RETURN
      END
      SUBROUTINE DERIVE(Y)
      DIMENSION Y(6)
      DIMENSION ET(50),ED(50),VT(50)
      REAL LAMBDR,LAMBDS,M
      COMMON LAMBDR,LAMBDS,M,ALPHAR,ALPHAS,NC,ET,ED,PAI,GRAVAC,VT,IK,
     *ICHEK,ISLOT,SPACJ,SQROTM,CLAM2,NSTRAT,H
      COMMON YY(6),YP(6),S,DS
      IF(NSTRAT.NE.0)GO TO 70
C
C  COMPUTATION OF DENSITY AND TEMPRATURE GRADIENTS AT Y
C
      YVAL=Y(6)
  814 IF(YVAL.LE.VT(1))GO TO 811
      IF(YVAL.GE.VT(NC))GO TO 813
      IF(YVAL-VT(IK))800,801,802
  801 EDD=(ED(IK)+ED(IK-1))*0.5
      ETT=(ET(IK)+ET(IK-1))*0.5
      IK=IK+1
      GO TO 70
  800 IK=IK-1
      IF(YVAL-VT(IK))800,801,805
  805 EDD=ED(IK)
      ETT=ET(IK)
      IK=IK+1
      GO TO 70
  802 IK=IK+1
      IF(IK.LE.NC)GO TO 814
      WRITE(6,808)
  808 FORMAT(10X,25H THIS IS THE FREE SURFACE./)
      RETURN
  811 EDD=ED(1)
      ETT=ET(1)
      GO TO 70
  813 EDD=ED(NC-1)
      ETT=ET(NC-1)
   70 SQROTM=SQRT(Y(2)*Y(2)+H*H)
```

```
      IF(ISLOT.GT.0)GO TO 72
C
C  ROUND JET SOLUTION
C
      ENTRAN=2.*ALPHAR*SQRT(2.*PAI*SQROTM)
      CLAM2=2.*LAMBDR*LAMBDR
      CLAM=(1.+LAMBDR*LAMBDR)/2.
      GO TO 73
C
C  SLOT JET SOLUTION
C
   72 CLAM2=LAMBDS*1.414214
      CLAM=SQRT((1.+LAMBDS*LAMBDS)/2.)
      ENTRAN=2.82842*ALPHAS*SPACJ*SQROTM/Y(1)
   73 YP(1)=ENTRAN
      YP(5)=H/SQROTM
      YP(6)=Y(2)/SQROTM
      YP(2)=CLAM*GRAVAC*Y(1)*Y(3)/SQROTM
      IF(NSTRAT.NE.0)RETURN
      YP(3)=Y(1)*EDD*YP(6)
      YP(4)=Y(1)*ETT*YP(6)
      RETURN
      END
      SUBROUTINE RUNGS
      COMMON LAMBDR,LAMBDS,M,ALPHAR,ALPHAS,NC,ET,ED,PAI,GRAVAC,VT,IK,ICH
     1EK,ISLOT,SPACJ,SQROTM,CLAM2,NSTRAT,HV
      COMMON Y(6),YPRIME(6),X,H
      REAL LAMBDR,LAMBDS,M
      DIMENSION ET(50),ED(50),VT(50)
      DIMENSION Z(6),W1(6),W2(6),W3(6),W4(6)
C
C  RUNGS - RUNGE KUTTA SOLUTION OF SET OF FIRST ORDER O.D.E.
C  DIMENSIONS MUST BE SET FOR EACH PROGRAM
C  X   INDEPENDENT VARIABLE
C  H   INCREMENT DELTA X,MAYBE CHANGED IN VALUE
C  N   NUMBER OF EQUATIONS
C  Y   DEPENDENT VARIABLE BLOCK ONE DIMENSIONAL ARRAY
C  YPRIME  DERIVATIVE BLOCK  ONE DIMENSIONAL ARRAY
C  THE PROGRAMMER MUST SUPPLY INITIAL VALUES OF Y(1) TO Y(N)
C  INDEX IS A VARIABLE WHICH SHOULD BE SET TO ZERO BEFORE EACH
C  INITIAL ENTRY TO THE SUBROUTINE, I.E., TO SOLVE A DIFFERENT
C  SET OF EQUATIONS OR TO START WITH NEW INITIAL CONDITIONS.
C  THE PROGRAMMER MUST WRITE A SUBROUTINE CALLED DERIVE WHICH
C  COMPUTES THE DERIVATIVES AND STORES THEM
C  THE ARGUMENT LIST IS SUBROUTINE DERIVE(X,N,Y,YPRIME)
      DO 2 I=1,6
      W1(I)=H*YPRIME(I)
    2 Z(I)=Y(I)+(W1(I)*.5)
      CALL DERIVE(Z)
      DO 3 I=1,6
      W2(I)=H*YPRIME(I)
    3 Z(I)=Y(I)+.5*W2(I)
```

```
      CALL DERIVE(Z)
      DO 4 I=1,6
      W3(I)=H*YPRIME(I)
    4 Z(I)=Y(I)+W3(I)
      CALL DERIVE(Z)
      DO 7 I=1,6
      W4(I)=H*YPRIME(I)
    7 Y(I)=Y(I)+(((2.*(W2(I)+W3(I)))+W1(     +(I))/6.)
      X=X+H
      CALL DERIVE(Y)
      RETURN
      END
```

Appendix B

Shirazi
Surface Discharge
Model

```
30SHIRAZI                                                        JANUARY 9, 1975

30SHIRAZI      SHIRAZI PDS PROGRAM                         6 _
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```
C      PROGRAM POS                                                      00001
C.....FILE NAME (FORTRAN PROGRAM): 30SHIRAZI ..............................
C.....INPUT DATA FILE            : 30SHIRAZI-DT ...........................
C.....TERMINAL JOB ENTRY FILE    : 30SHIRAZIJCL ...........................
      DIMENSION W(2)                                                    00002
      COMMON E,CO,CF,FM,EV,GP,DR,AK,V,A,DS,P,SP,S2,RF                   00003
      COMMON THO,FRO,FS,INFO(20),NLINE,XK1                              00004
      COMMON  Y(7), D(7), PRMT(5), AUX(20,7),AP(20),YY(8),IHLF,S        00005
      COMMON U1,S1,TIME,TO,TC,UO,HO                                     00006
      COMMON/IDASH/Y2LAST,ID                                            00007
      EQUIVALENCE (Y(1),D), (Y(2),T), (Y(3),TH), (Y(4),B), (Y(5),H)    00008
      EQUIVALENCE (Y(6),XP), (Y(7),YP)                                  00009
      REAL H,LHS                                                        00010
      P=3.1415927
      SP=SQRT(P)
      S2=SQRT(2.)
      READ(5,3) NCASE,DS,CD,CF,F,AK,EV,FM,XK1                           00011
C ID=DEGREE ISOTHERM PRINT OUT,  NCASE=CASES TO BE STUDIED,E.G. SITES #.  00012
      DO 103 MANY=1,NCASE                                               00013
      READ(5,2) (INFO(I),I=1,20)                                        00014
      READ(5,1) ID,KV,KW,KA,DTHE,SLIM                                   00015
      KNT=0                                                             00016
    1 FORMAT (4I3,F8.2,F10.4)                                           00017
    2 FORMAT (20A4)                                                     00018
    3 FORMAT (2X,I2,F6.2,7F10.4)                                        00019
    9 FORMAT (4F10.3)                                                   00020
   17 FORMAT ('1',5X,20A4,I2,' DEGREE F ISOTHERM PRINT OUT.')           00021
      DO 103 MK=1,KV                                                    00025
      READ (5,9) TC,HO1,WO                                              00026
      DO 103 KK=1,KW                                                    00027
      READ(5,9) WATTM,VA,DELT,THETAI                                    00028
      THETI=THETAI                                                      00029
      TO=TC+DELT                                                        00030
      QO=WATTM*600./(3.4862.4*DELT)                                     00031
   20 FORMAT('ORUN #',I2,'  LOAD =',F10.0,'MEGA WATT',10X,F10.4,'DEGREE  00032
     1F(DELTA T.)',10X,F10.1,'CU FT/SEC(DISCHARGE)')                    00033
C FIND INITIAL FROUDE NUMBERS                                           00034
      HO=HO1                                                            00035
      I=1                                                               00036
      TT=TO                                                             00037
    7 T1=(TT-32.)*5./9.                                                 00038
      W(I)=1.-(T1**2*0.-T1*3.**7.)*0.000001                             00039
      IF(I.GE.2)GO TO 8                                                 00040
      I=2                                                               00041
      TT=TC                                                             00042
      GO TO 7                                                           00043
    8 DW=(W(2)-W(1))*32.17/W(2)                                         00044
    6 UO=QO/(WO*HO)                                                     00045
      FRO=UO/SQRT(DW*HO)                                                00046
      IF(FRO.GE.1.)GO TO 5                                              00047
      HO=HO*0.95                                                        00048
      GO TO 6                                                           00049
```

```
C      SET INITIAL CONSTANTS                                            00050
    5 RE=UO*HO/1.[illegible]E-5                                         00051
      V=VA/UO                                                           00052
      A=WO/HO                                                           00053
      FS=FRO*FRO                                                        00054
      GP=1.0/FS                                                         00055
      IF(ID.LE.1) ID=0                                                  00056
  102 DO 101 LK=1,KA                                                    00057
      Y2LAST=1.                                                         00058
      S1=0.                                                             00059
      U1=1.                                                             00060
      TIME=0.                                                           00061
        D=A                                                             00062
        U=1.                                                            00063
        T=1.                                                            00064
        B=A/2.                                                          00065
        H=1.                                                            00066
      THETI=THETI+DTHE                                                  00067
      KNT=KNT+1                                                         00068
      WRITE(6,17)(INFO(I),I=1,20),ID                                    00069
      WRITE(6,20)KNT,WATTM,DELT,QO                                      00070
        XP=0.                                                           00071
        YP=0.                                                           00072
      CALL SHEF(0)                                                      00073
C     CALCULATE CONDITIONS AT END OF DEVELOPMENT ZONE                   00074
      S1=5.*FRO**(-.33)*A**(.66)                                        00075
      B1=((1.+A*S1*FS/A*(FS-1.0)**1.5)**.667+1.)*B/FS                   00076
      H1=HO*B/B1                                                        00077
      THO=1.5708*THETI/90.0                                             00078
      W=A*(1.+.5*GP)                                                    00079
      STH = SIN(THO)                                                    00080
      CTH = COS(THO)                                                    00081
      N=0                                                               00082
      J=0                                                               00083
      DELW=0.1                                                          00084
      FD = 0.5*CD*V*ABS(V)*STH*STH*S(B*(1.+H))/2.0                      00085
      RV = SQRT(U*U - 2.0*U*V*CTH + V*V)                                00086
      IF(V.EQ.0.0 .OR. CF.EQ.0.0) GO TO 17                              00087
      SF=CF*F*(1.5*A*H(1)*RV**2/0.0206/(F*RV*(1.+H))**.5)**.25          00088
      SFX = SF*(V-U*CTH)/RV                                             00089
      SFY = -SF*U*STH/RV                                                00090
      GO TO 19                                                          00091
   17 SFX = 0.0                                                         00092
      SFY = 0.0                                                         00093
C     CALCULATE INITIAL ANGLE                                           00094
   19 TH=ATAN((A*STH-FD*CTH*SFY)/(H*CTH*U*V*(2./T-1.)*FD*STH*SFX))      00095
      IF (TH.LT.0.0) TH=P+TH                                            00096
C     CALCULATE INITIAL THICKNESS AND WIDTH , H AND B                   00097
      LHS=H*COS(TH-THO)*V*Q*(2./T-1.)*COS(TH)*(SFX*FD*SIN(THO))*COS(TH)+ 00098
     1 (SFY-FD*COS(THO))*SIN(TH)                                        00099
      IF(LHS.LE.0.) GO TO 32                                            00100
   19 BB=(FS*LHS*B)/(SP*T*A**2)*3.2)**(1./3.)                           00101
```

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```
   33 DIF=8.0/T**2*A/P*SP*BM**5*T*GP*A*A/B1/B.-LHS*RM**2
      IF(ABS(DIF/LHS).LT.0.0001)GO TO 36
      IF(DIF.GE.0.0 .AND. N.EQ.0)GO TO 32
      IF(RM.GT.5.0 .AND. N.EQ.0)DELM=DELM*10.
      IF(N.EQ.0)GO TO 35
      IF(DIF1*DIF.LT.0.)GO TO 34
   35 RM=RM+DELM
      DIF1=DIF
      N=1
      GO TO 33
   34 IF(J.GE.5)GO TO 36
      DELM=-0.1*DELM
      J=J+1
      GO TO 35
   32 WRITE(6,5)N
    5 FORMAT(' ASSUMING UPSTREAM WEDGE PRESENT--USING F=1.02',5X,I4)
      RM = 1.
      C=3.08
      CC=1.-1./C
      A1=8.*Q**4*GP*C/T**3/(P*SP*LHS**3*CC**2)
      H1=SP*LHS**2*CC/(2.*Q**2*GP*C/T)
C
C     CALCULATE INITIAL VALUES OF Q,X,Y
   36 XP = XP + SI*COS(TH)
      YP = YP + SI*SIN(TH)
      B=B1*BM
      H=H1*RM
      Q = 2.0*Q/T
      THO = 90.0*THO/1.5707963
C       ASSIGN VALUES TO PARAMETERS IN SUBROUTINES OUTP AND RHPCG
      NLINE=0
      PRMT(1)=SI
      PRMT(2) = SLIM
      PRMT(3) = DS
      PRMT(4) = 0.01
      DO 45 I=1,7
   45 D(I) = 0.1
      D(4) = 0.25
      D(5) = 0.25
      IST=0
C
      CALL RHPCG
C     WRITE AREAS WITHIN ISOTHERMS
      WRITE (6,200) WATTM,DELT
  200 FORMAT (1H0,/////,5X,' A R E A S  O F  E X C E S S  T E M P E R A
     1T U R E  F O R',6X,2F15.4)
      WRITE (6,201)
  201 FORMAT (//,5X,'TEMP.(F)  ',5X,'AREA (FT**2)'/)
      TX=DELT*T
      DO 90 I=1,20
      TI=FLOAT(I)/20.
      TJ=TI*(T0-TC)
```

PAGE 4 GDE FILE 3DSHIRAZI

```
         IF(T.GT.TI) GO TO 301
         WRITE(6,202) TJ,AR(I)
         GO TO 90
301   WRITE(6,302)TJ,AR(I),TX
302   FORMAT(6X,F5.2,5X,1PE10.3,2X,'PARTIAL AREA - CALCULATION VALID TO
     1 T =',0PF6.3)
90          CONTINUE
  202 FORMAT (6X,F5.2,5X,1PE10.3)
  131 CONTINUE
  130 CONTINUE
      STOP
      END
      SUBROUTINE AREA(J)
      COMMON F,CD,CF,FM,FV,GP,DR,AK,V,AM,DSS,P,SP,S2,RF
      COMMON THO,FRO,FS,INFO(20),NLINE,AK1
      COMMON  Y(7), D(7), PRMT(5), AUX(20,7),A(20),YY(8),IHLF,S
      COMMON Q1,S1,TIME,T0,TC,U0,H0
      EQUIVALENCE (Y(1),Q), (Y(2),T), (Y(3),TH), (Y(4),B), (Y(5),H)
      EQUIVALENCE (Y(6),XP), (Y(7),YP)
      DIMENSION  W1(20), W2(20)
      IF(J.GT.0)GO TO 20
      INITIALIZE VARIABLES A AND W1
      DO 15 I=1,20
      A(I) = 0.0
   15 W1(I) = H*H0
      SLAST=0.
      GO TO 150
      CALCULATE AREAS
   20 DS=S-SLAST
      DO 100 I=1,20
      TI = I/20.0
      IF(TI.LE.T)GO TO 40
      W2(I) = 0.0
      GO TO 50
   40 W2(I) = H*H0*SQRT(ALOG(T/TI))
   50 A(I) = A(I) + (W2(I) + W1(I))*DS*H0
  100 W1(I) = W2(I)
      SLAST=S
  150 CONTINUE
      RETURN
      END
      SUBROUTINE FCT
      COMMON F,CD,CF,FM,FV,GP,DR,AK,V,A,DS,P,SP,S2,RF
      COMMON THO,FRO,FS,INFO(20),NLINE,AK1
      COMMON  Y(7), D(7), PRMT(5), AUX(20,7),AR(20),YY(8),IHLF,S
      COMMON Q1,S1,TIME,T0,TC,U0,H0
      EQUIVALENCE (Y(1),Q), (Y(2),T), (Y(3),TH), (Y(4),B), (Y(5),H)
      EQUIVALENCE (Y(6),XP), (Y(7),YP)
      CTH = COS(TH)
      STH = SIN(TH)
      VCT = V*CTH
      VST = V*STH
      FA = GP*R*SP*0.5*H*H
      DE = GP*T*H*B*R*SP
      HM = J*Q/(H*H*R)
      FD = CD*H*VST*ABS(V)*STH/S2
      U = 2.0*(Q/(P*B*H) - VCT)
      J=7
      F=U**2/(P*SP*GP*T*H*(H*B)**2)
C     IF  Q,T,TH,R, OR H ARE NEGATIVE, RETURN
      DO 5 I=1,5
      IF (Y(I)) 50,5,5
    5 CONTINUE
C     CALC HORIZONTAL AMBIENT AND JET ENTRAINMENT
      FA = EH
      QA = 1.5*P*FA*H/R
      RV = U*U + VST*VST
      QJ = SP*E*SQRT(RV)*H
      QH = QA + QJ
C     CALC VERTICAL AMBIENT ENTRAINMENT
      RI = GP*S2*T*H/(U*VCT)**2
      CALL REF(RI,RF)
      QA = 1.5*P*R*EV*EA*RF/H
C     CALC VERTICAL JET ENTRAINMENT AND INTERFACIAL SHEAR
      QJ = 0.0
      SFX = 0.0
      SFY = 0.0
      DO 25 I=1,10
      VI=EXP(-2.0*(0.1*I-0.05)**2)
      RV = U*U*VI*VI + VST*VST
      RI = GP*S2*T*VI*H/RV
      CALL REF(RI,RF)
      DQ = 2.0*P*RF*E*SQRT(RV)*S2*R/10.0
      RV=RV**0.375
      IF(CF.EQ.0.0)GO TO 25
      SFX = SFX + RV*(VST*STH - U*VI*CTH)
      SFY = SFY + RV*(VCT + U*VI)
   25 QJ=QJ+DQ
      QJ = QJ + 1.77*DQ
      QV = QA + QJ
      IF(CF.EQ.0.0) GO TO 10
      GN = SQRT(SQRT(1./(RE*H)))*0.0206*S2*R/10.0
      SFX=SFX*GN*2.0*CF
      SFY=-SFY*GN*2.0*CF*STH
C     CALC DERIVATIVES OF Q,T,TH,R,H,X, AND Y
   10 D(1) = QH + QV
      D(2) = -T*(2.0*SP*A*H*R + D(1))/Q
      DTH=-FD+SFY*CTH-SFX*STH-VST*D(1)
      D(3) = DTH/(Q*Q/(P*R*H) + GP*T*H*H*R*SP/2.0)
      IF(F.LT.1.0) F=1.001
      D(4)=KK1/(SQRT(R*F/H-1.0))
      DR=SFY*R*STH+SFX*R*CTH+(R*VCT-2.0*Q/(R*H))*D(1)
      DH = DR - FA*R*D(2)
      DR = -DR/((QV/QH+1.0)*HE*H)*R
```

```
      D(4)=D(4)*CR
      DH=DH+J*J*D(4)/(R*R*H)-FA*T*D(4)
      D(5) = DH/(DE-HE)
      D(6) = CTH
      D(7) = STH
   50 CONTINUE
      RETURN
      END
      SUBROUTINE REF(RI,RF)
      IF (RI.GT.0.4) GO TO 10
      EN=EXP(-4.0)
      RF=(EXP(-5.0*RI)-EN)/(1.0-EN)
      GO TO 20
   10 RF = 0.0
   20 CONTINUE
      RETURN
       END
        SUBROUTINE OUTP
      COMMON F,CD,CF,FH,FV,GP,DH,AE,V,A,DS,P,SP,S2,RF
      COMMON THT,FHO,FS,INFO(20),NLINE,KK1
      COMMON  Y(7), D(7), PRNT(5), AUX(20,7),AR(20),YY(8),IHLF,S
      COMMON U1,S1,TIME,TO,TC,UO,HO
      COMMON/IDASH/Y2LAST,IO
      EQUIVALENCE (Y(1),Q), (Y(2),T), (Y(3),TH), (Y(4),R), (Y(5),H)
      EQUIVALENCE (Y(6),XP), (Y(7),YP)
      IF(HO.LE.0.)GO TO 29
C     IS NUMBER OF LINES 250.
      Y2LAST=Y
      IF (NLINE.GT.0)GO TO 11
      WRITE(6,1)
    1 FORMAT(//,' FLOATING WARM WATER JETS --'/)
      WRITE(6,2)FRO,A,V,THO,HO,TC
    2 FORMAT(1X,'FR0 = ',F5.1,5X,'R0/H0 =',F5.1,5X,'V/U0 =',F7.3,
     15X,'ANGLE =',F5.1,5X,'DISC.DEP.=',F7.3,5X,'AMB.TEMP=',F7.3/)
      WRITE(6,3)F,CD,CF,RE,EV,FH,AR
    3 FORMAT(1X,'F =',F7.4,3X,'CD =',F7.4,3X,'CF =',F7.4,3X,'RE =',F10.3
     1,3X,'EV =',F10.3,3X,'FH =',F10.3,3X,'SUR.HT.EXC.CO.=',F10.3//)
      WRITE (6,4) IO,IO,IO
    4 FORMAT (5X,'S',7X,'X',7X,'Y',5X,'TH',5X,'T',6X,'U',6X,' Q ',6X,
     1'H',5X,' H ',5X,' R ',6X,'B ',5X,'RI',6X,I2,'D.Q',2X,I2,'D.DEP',
     2I2,'D.-IO',' IHLF')
C     NUMBER OF LINES LESS THAN 250 , CALCULATE AND WRITE OUTPUT DATA
   11 NLINE = NLINE + 1
      CALL AREA(I)
      U = 2.0*(Q/(P*R*H) - V*COS(TH))
      F = (U*0.5 + V*COS(TH))*SQRT(SP/(GP*T*H))
      RV = U*U + (V*SIN(TH))**2
      RI = GP*T*H*S2/RV
      UVCT = U + V*COS(TH)
C     TIME=TIME+2.*(S-S1)/(U1+UVCT)
      U1=UVCT
      S1=S
      THOUT= Y(3)*90.0/1.5707963
      TP=(TO-TC)*T
      UC=UO*U
      DEP=HO*H
      WID=HO*B
      QOUT=Q*UO*HO**2
      HT=QOUT*TP/2.
      Z=S*HO
      XH=XP*HO
      YH=YP*HO
      IF(ID.LE.1) GO TO 6
      XI=XH+WID*SIN(TH)
      XO=XH-WID*SIN(TH)
      YI=YH-WID*COS(TH)
      YO=YH+WID*COS(TH)
      TS=ID
      IF(TP.LE.TS)GO TO 6
      SQTS=SQRT(ALOG(TP/TS))
      DPS=DEP*SQTS
      WDS=WID*SQTS
      XSI=XH+WDS*SIN(TH)
      XSO=XH-WDS*SIN(TH)
      YSI=YH-WDS*COS(TH)
      YSO=YH+WDS*COS(TH)
      QS=(U*ERF(SQTS)**2*1.5707963*UF*H*WID+V*COS(TH)*DPS*WDS*2.)*UO
      GO TO 7
    6 DPS=0.
      WDS=0.
      XSI=0.
      YSI=0.
      XSO=0.
      YSO=0.
      QS=0.
    7 WRITE(6,5)Z,XH,YH,THOUT,TP,UC,QOUT,HT,DEP,WID,F,RI,QS,DPS,WDS,IHLF
C     IF(ID.GT.1)WRITE(6,8)XI,YI,XO,YO,ID,XSI,YSI,XSO,YSO
    5 FORMAT (3(1X,F7.1),F6.1,1X,2(F6.3,1X),1X,F9.2,1X,F9.2,1X,F5.2,
     1 1X,F7.1,2(1X,F6.3),1X,F9.2,1X,F5.2,1X,F7.1,1X,I3)
    8 FORMAT(5X,'(XI,YI)=(',2F8.2,')  (XO,YO)=(',2F8.2,')',4X,I2,'DEG IS
     1OTH--(XI,YI)=(',2F8.2,')  (XO,YO)=(',2F8.2,')')
C     PUT PRMT(5)= 1.0  IF NUMERICAL INTEGRATION SHALL STOP
   24 IF(TP.LT.3.0 .OR.H.LE.0.01)PRMT(5)=1.0
      IF (NLINE.GE.300 .OR. IHLF.GT.10)PRMT(5)=1.0
      IF(H.LT.0.1) WRITE (6,10)H
   10 FORMAT(//,'  H =',E10.4)
      RETURN
      END
      SUBROUTINE KHPCG
      COMMON E,CO,CF,FH,EV,GP,DR,AK,V,AM,DS,P,SP,SZ,RE
      COMMON THO,PRO,FS,INFO(20),NLINE,XX1
      COMMON  Y(7), DERY(7), PRMT(5), AUX(20,7),A(20),YY(8),IHLF,X
      COMMON U1,S1,TIME,TO,TC,UO,HO
      COMMON/IDASH/Y2LAST,ID
```

```
      N=1
      NDIM=7
      IHLF=0
      X=PRMT(1)
      H=PRMT(3)
      PRMT(5)=0.
      DO 1 I=1,NDIM
      AUX(16,I)=0.
      AUX(15,I)=DERY(I)
    1 AUX(1,I)=Y(I)
      IF(H*(PRMT(2)-X))3,2,4
C     ERROR RETURNS
    2 IHLF=12
      GO TO 4
    3 IHLF=13
C     COMPUTATION OF DERY FOR STARTING VALUES
    4 CALL FCT
C     RECORDING OF STARTING VALUES
      CALL OUTP
      IF(PRMT(5))6,7,6
    6 RETURN
    7 DO 8 I=1,NDIM
    8 AUX(8,I)=DERY(I)
C     COMPUTATION OF AUX(2,I)
      ISW=1
      GO TO 100
    9 X=X+H
      DO 10 I=1,NDIM
   10 AUX(2,I)=Y(I)
C     INCREMENT IS TESTED BY MEANS OF BISECTION
   11 IHLF=IHLF+1
      X=X-H
      DO 12 I=1,NDIM
   12 AUX(4,I)=AUX(2,I)
      H=.5*H
      N=1
      ISW=2
      GO TO 100
   13 X=X+H
      CALL FCT
      N=2
      DO 14 I=1,NDIM
      AUX(2,I)=Y(I)
   14 AUX(9,I)=DERY(I)
      ISW=3
      GO TO 100
C     COMPUTATION OF TEST VALUE DELT
   15 DELT=0.
      DO 16 I=1,NDIM
      IF(Y(I).LT.0.AND.I.NE.6)GO TO 17
   16 DELT=DELT+AUX(15,I)*ABS(Y(I)-AUX(4,I))
      DELT=.066666667*DELT
```

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```
      IF(DELT.LT.PRMT(4).AND.Y2LAST-Y(2).LE..05)GO TO 19
   17 IF(IHLF-10)11,18,18
C     NO SATISFACTORY ACCURACY AFTER 10 BISECTIONS.  ERROR MESSAGE
   18 IHLF=11
      X=X+H
      GO TO 4
C     THERE IS SATISFACTORY ACCURACY AFTER LESS THAN 11 BISECTIONS
   19 X=X+H
      CALL FCT
      DO 20 I=1,NDIM
      AUX(3,I)=Y(I)
   20 AUX(10,I)=DERY(I)
      N=3
      ISW=4
      GO TO 100
   21 N=1
      X=X+H
      CALL FCT
      X=PRMT(1)
      DO 22 I=1,NDIM
      AUX(11,I)=DERY(I)
   22 Y(I)=AUX(1,I)+H*(.375*AUX(8,I)+.7916666667*AUX(9,I)
     X-.2083333333*AUX(10,I)+.0416666667*DERY(I))
   23 X=X+H
      N=N+1
      CALL FCT
      CALL OUTP
      IF(PRMT(5))6,24,6
   24 IF(N-4)25,200,200
   25 DO 26 I=1,NDIM
      AUX(N,I)=Y(I)
   26 AUX(N+7,I)=DERY(I)
      IF(N-3)27,29,200
   27 DO 28 I=1,NDIM
      DELT=AUX(9,I)*4.
   28 Y(I)=AUX(1,I)+H*(AUX(8,I)+DELT+AUX(10,I))/3.0
      GO TO 23
   29 DO 30 I=1,NDIM
      DELT=(AUX(9,I)+AUX(10,I))*3.
   30 Y(I)=AUX(1,I)+.375*H*(AUX(8,I)+DELT+AUX(11,I))
      GO TO 23
C     THE FOLLOWING PART OF SUBROUTINE HPCG COMPUTES BY MEANS OF
C     RUNGE-KUTTA METHOD STARTING VALUES FOR THE NOT SELF-STARTING
C     PREDICTOR-CORRECTOR METHOD
  100 DO 101 I=1,NDIM
      AUX(5,I)=H*AUX(N+7,I)
C     Z IS AN AUXILIARY STORAGE LOCATION
  101 Y(I)=AUX(N,I)+.4*AUX(5,I)
      Z=X
      X=Z+.4*H
      CALL FCT
      DO 102 I=1,NDIM
```

```
      AUX(6,I)=H*DERY(I)
  102 Y(I)=AUX(N,I)+.29697760924*AUX(5,I)+.15875964497*AUX(6,I)
      X=Z+.45573725*H
      CALL FCT
      DO 103 I=1,NDIM
      AUX(7,I)=H*DERY(I)
  103 Y(I)=AUX(N,I)+.21810038822*AUX(5,I)-3.05096514869*AUX(6,I)
     1  +3.83286476046*AUX(7,I)
C
      X=Z+H
      CALL FCT
      DO 104 I=1,NDIM
  104 Y(I)=AUX(N,I)+.17476028226*AUX(5,I)-.55148066287*AUX(6,I)
     X+1.20553559965*AUX(7,I)+.17118478122*H*DERY(I))
      X=Z
      GO TO (9,13,15,21),ISW
C
C     POSSIBLE BREAK-POINT FOR LINKAGE
C
C     STARTING VALUES ARE COMPUTED.
C     NOW START HAMMINGS MODIFIED PREDICTOR-CORRECTOR METHOD
  200 ISTEP=3
  201 IF(N-8)204,202,204
C
C     N=8 CAUSES THE ROWS OF AUX TO CHANGE THEIR STORAGE LOCATIONS
  202 DO 203 N=2,7
      DO 203 I=1,NDIM
      AUX(N-1,I)=AUX(N,I)
  203 AUX(N+6,I)=AUX(N+7,I)
      N=7
C
C     N LESS THAN 8 CAUSES N+1 TO GET N
  204 N=N+1
C
C     COMPUTATION OF NEXT VECTOR Y
      DO 205 I=1,NDIM
      AUX(N-1,I)=Y(I)
  205 AUX(N+6,I)=DERY(I)
      X=X+H
  206 ISTEP=ISTEP+1
      DO 207 I=1,NDIM
      DELT=AUX(N-4,I)+1.3333333333*H*(AUX(N+6,I)+AUX(N+6,I)-
     *  AUX(N+5,I)+AUX(N+4,I)+AUX(N+4,I))
      Y(I)=DELT-.9256198*AUX(16,I)
  207 AUX(16,I)=DELT
C     PREDICTOR IS NOW GENERATED IN ROW 16 OF AUX, MODIFIED PREDICTOR
C     IS GENERATED IN Y.  DELT MEANS AN AUXILIARY STORAGE
C
      CALL FCT
C     DERIVATIVE OF MODIFIED PREDICTOR IS GENERATED IN DERY
C
      DO 208 I=1,NDIM
      DELT=.125*(9.*AUX(N-1,I)-AUX(N-3,I)+3.*H*(DERY(I)+AUX(N+6,I)+
     X AUX(N+6,I)-AUX(N+5,I)))
      AUX(16,I)=AUX(16,I)-DELT
  238 Y(I)=DELT+.07438017*AUX(16,I)
C
C  TEST WHETHER H MUST BE HALVED OR DOUBLED
      DELT=0.
      DO 209 I=1,NDIM
  209 DELT=DELT+AUX(15,I)*ABS(AUX(16,I))
      IF(DELT.GT.PRMT(4).OR.Y2LAST-Y(2).GT..05)GO TO 222
C
C  H MUST NOT BE HALVED.  THAT MEANS Y(I) ARE GOOD
  210 CALL FCT
      CALL OUTP
      IF(PRMT(5))212,213,212
  212   TURN
  213 IF(H*(X-PRMT(2)))214,212,212
  214 IF(ABS(X-PRMT(2))-.1*ABS(H))212,215,215
  215 IF(DELT-.02*PRMT(4))216,216,201
C
C
C
C  H COULD BE DOUBLED IF ALL NECESSARY PRECEEDING VALUES ARE
C  AVAILABLE
  216 IF(IHLF)201,217,217
  217 IF(N-7)201,218,218
  218 IF(ISTEP-4)201,219,219
  219 IMOD=ISTEP/2
      IF(ISTEP-IMOD-IMOD)201,220,201
  220 H=H+H
      IHLF=IHLF-1
      ISTEP=0
      DO 221 I=1,NDIM
      AUX(N-1,I)=AUX(N-2,I)
      AUX(N-2,I)=AUX(N-4,I)
      AUX(N-3,I)=AUX(N-6,I)
      AUX(N+6,I)=AUX(N+5,I)
      AUX(N+5,I)=AUX(N+3,I)
      AUX(N+4,I)=AUX(N+1,I)
      DELT=AUX(N+6,I)+AUX(N+5,I)
      DELT=DELT+DELT+DELT
  221 AUX(16,I)=8.962963*(Y(I)-AUX(N-3,I))-3.361111*H*(DERY(I)+DELT
     1 +AUX(N+4,I))
      GO TO 201
C
C
C  H MUST BE HALVED
  222 IHLF=IHLF+1
      IF(IHLF-10)223,223,210
  223 H=.5*H
      ISTEP=0
      DO 224 I=1,NDIM
```

```
      Y(I)=.00390625*(80.*AUX(N-1,I)+135.*AUX(N-2,I)+40.*AUX(N-3,I)+
     1AUX(N-4,I))-.1171875*(AUX(N+6,I)-6.*AUX(N+5,I)-AUX(N+4,I))*H
      AUX(N-4,I)=.00390625*(12.*AUX(N-1,I)+135.*AUX(N-2,I)+
     1108.*AUX(N-3,I)+AUX(N-4,I))-.0234375*(AUX(N+6,I)+18.*AUX(N+5,I)-
     29.*AUX(N+4,I))*H
      AUX(N-3,I)=AUX(N-2,I)
  224 AUX(N+4,I)=AUX(N+5,I)
      X=X-H
      DELT=X-(H+H)
      CALL FCT
      DO 225 I=1,NDIM
      AUX(N-2,I)=Y(I)
      AUX(N+5,I)=DERY(I)
  225 Y(I)=AUX(N-4,I)
      DELT=DELT-(H+H)
      CALL FCT
      DO 226 I=1,NDIM
      DELT=AUX(N+5,I)+AUX(N+4,I)
      DELT=DELT+DELT+DELT
      AUX(16,I)=8.962963*(AUX(N-1,I)-Y(I))-3.361111*H*(AUX(N+6,I)+DELT
     X +DERY(I))
  226 AUX(N+3,I)=DERY(I)
      GO TO 206
      END
```

Appendix C

Calculational Results

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    PLANT SITE #1 AT OAHE RESERVOIR: CAPACITY=4000MW. LOW LEVEL.

  4000.MEGA WATT      600.-PORT DISCH.         4.79VOL/SEC/JET

ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

    JET DIAMETER=  1.33FEET
    JET DISCHARGE TEMPERATURE= 83.000EGREE FAHREN      JET DISCHARGE VELOCITY=  3.40FEET/SEC
    JET DISCH. ANGLE= 20.00 DEGREES                    JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
    JET SPACING C-C=  5.00FEET                         JET DISCHARGE DEPTH= 15.00FEET
                                                       WATER BODY DEPTH =  16.0FEET
    X         Y      WIDTH  DILUTION     Q     DELTA-TEMP       S   LOCAL FRD   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

   7.771    2.829    2.668    1.001      9.5  21.7753296    8.270     50.33    20.00     3.081     2.655     1.931
  10.249    3.811    3.865    1.467     13.9  14.8534107   10.936     24.85    23.43     4.010     3.308     1.994
  12.694    4.959    5.020    1.960     18.6  11.2315476   13.603     15.55    27.75     4.731     3.705     1.403
  14.959    6.298    6.117    2.423     23.0   8.9925604   16.269     11.28    32.62     5.257     3.844     0.0
           TRANSITION POINT TWO
  17.143    7.820    8.933    2.888     27.4   6.1207361   18.935      4.45    37.02     5.336     2.841     0.0
  19.205    9.504   11.045    3.310     31.4   5.3402462   21.601      3.54    41.28     5.931     2.004     0.0
POINT OF IMPINGEMENT (DOWNSTREAM ) H1= 8.53  U1= 0.80  Q2=   11.9  FH1= 0.76  FH2= 0.27 )
                     UPSTREAM ) H1=-0.00  U1= 0.0   Q2=   17.4  FH1= 0.0   FH2= 0.39 )
NOTE: THE VALUES OF H1,UA,Q2 AND FH2 ARE NOT NECESSARILY CORRECT BECAUSE IN THIS APPROXIMATE ANALYSIS THE VALUE WE NEED IS FH1.
  20.935   10.733   12.376    3.583     34.0   6.9362413   23.416      3.19    44.03     6.173     0.0       0.0
    STAGNANT WEDGE OR COUNTER FLOW SYSTEM IS EXPECTED IN THE FLOW AWAY REGION BASED ON JIRKA AND HARLEMAN. FH= 0.514
```

```
    PLANT SITE #1 AT OAHE RESERVOIR: CAPACITY=4000MW. AVERAGE LEVEL.

  4000.MEGA WATT      600.-PORT DISCH.         4.79VOL/SEC/JET

ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

    JET DIAMETER=  1.33FEET
    JET DISCHARGE TEMPERATURE= 83.000EGREE FAHREN      JET DISCHARGE VELOCITY=  3.40FEET/SEC
    JET DISCH. ANGLE= 20.00 DEGREES                    JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
    JET SPACING C-C=  5.00FEET                         JET DISCHARGE DEPTH= 21.00FEET
                                                       WATER BODY DEPTH =  22.0FEET
    X         Y      WIDTH  DILUTION     Q     DELTA-TEMP       S   LOCAL FRD   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

   7.773    2.829    2.669    1.001      9.5  21.7696533    8.272     50.30    20.01     3.082     2.659     1.931
  10.247    3.810    3.864    1.466     13.9  14.8586673   10.933     24.87    23.42     4.009     3.308     1.995
  12.693    4.956    5.320    1.960     18.6  11.2333517   13.600     15.56    27.75     4.731     3.704     1.406
  14.958    6.297    6.117    2.423     23.0   8.9926014   16.267     11.28    32.62     5.257     3.844     0.0
           TRANSITION POINT TWO
  17.144    7.823    8.936    2.888     27.4   6.1202021   18.934      4.44    37.02     5.336     2.841     0.0
  19.207    9.506   11.248    3.311     31.4   5.3394537   21.601      3.54    41.28     5.931     2.002     0.0
  21.144   11.331   12.978    3.708     35.2   4.7672081   24.268      3.07    45.28     6.245     0.0       0.0
  22.956   13.287   14.756    4.091     38.8   4.3214741   26.935      2.80    48.90     6.303     0.0       0.0
  24.845   15.365   16.606    4.464     42.4   3.9600086   29.601      2.65    52.13     6.112     0.0       0.0
POINT OF IMPINGEMENT (DOWNSTREAM ) H1= 9.70  U1= 0.90  Q2=   18.6  FH1= 0.69  FH2= 0.26 )
                     UPSTREAM ) H1= 0.00  U1= 0.0   Q2=   27.3  FH1= 0.0   FH2= 0.35 )
NOTE: THE VALUES OF H1,UA,Q2 AND FH2 ARE NOT NECESSARILY CORRECT BECAUSE IN THIS APPROXIMATE ANALYSIS THE VALUE WE NEED IS FH1.
  25.236   16.122   16.995    4.599     43.7   3.8436155   30.578      2.61    53.22     5.979     0.0       0.0
    STAGNANT WEDGE OR COUNTER FLOW SYSTEM IS EXPECTED IN THE FLOW AWAY REGION BASED ON JIRKA AND HARLEMAN. FH= 0.474
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```
    PLANT SITE NO.1 AT OAHE RESERVOIR: CAPACITY=4000MW. HIGH LEVEL.

  4000.MEGA WATT      600.-PORT DISCH.         4.79VOL/SEC/JET

ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

    JET DIAMETER=  1.33FEET
    JET DISCHARGE TEMPERATURE= 83.000EGREE FAHREN      JET DISCHARGE VELOCITY=  3.40FEET/SEC
    JET DISCH. ANGLE= 20.00 DEGREES                    JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
    JET SPACING C-C=  5.00FEET                         JET DISCHARGE DEPTH= 31.00FEET
                                                       WATER BODY DEPTH =  32.0FEET
    X         Y      WIDTH  DILUTION     Q     DELTA-TEMP       S   LOCAL FRD   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

   7.775    2.830    2.676    1.001      9.5  21.7601929    8.274     50.26    20.01     3.083     2.656     1.931
  10.253    3.812    3.867    1.468     13.9  14.8665385   10.940     24.83    23.43     4.011     3.309     1.996
  12.698    4.961    5.022    1.961     18.6  11.2269258   13.606     15.54    27.76     4.732     3.705     1.401
  14.962    6.300    6.120    2.424     23.0   8.9885788   16.272     11.28    32.63     5.258     3.846     0.0
           TRANSITION POINT TWO
  17.149    7.823    8.939    2.889     27.4   6.1182108   18.938      4.44    37.03     5.336     2.840     0.0
  19.211    9.537   11.352    3.312     31.4   5.3381119   21.603      3.54    41.29     5.931     1.999     0.0
  21.148   11.335   12.982    3.709     35.2   4.7662249   24.269      3.07    45.28     6.246     0.0       0.0
  22.984   13.296   14.763    4.092     38.9   4.3195601   26.938      2.80    48.91     6.303     0.0       0.0
  24.695   15.352   16.414    4.466     42.4   3.9584551   29.600      2.65    52.15     6.111     0.0       0.0
  26.238   17.503   17.973    4.835     45.9   3.6566093   32.269      2.56    55.02     5.653     0.0       0.0
  27.719   19.725   19.461    5.200     49.4   3.3993066   34.938      2.51    57.55     4.866     0.0       0.0
  29.105   22.007   20.896    5.564     52.9   3.1770191   37.607      2.48    59.79     3.538     0.0       0.0
  30.404   24.331   22.290    5.926     56.3   2.9830112   40.268      2.47    61.76     0.0       0.0       0.0
POINT OF IMPINGEMENT (DOWNSTREAM ) H1=10.12  U1= 1.16  Q2=   26.4  FH1= 0.61  FH2= 0.25 )
                     UPSTREAM ) H1=-0.01  U1= 0.0   Q2=   29.5  FH1= 0.0   FH2= 0.31 )
NOTE: THE VALUES OF H1,UA,Q2 AND FH2 ARE NOT NECESSARILY CORRECT BECAUSE IN THIS APPROXIMATE ANALYSIS THE VALUE WE NEED IS FH1.
  31.246   25.943   23.225    6.173     58.6   2.8636808   42.086      2.47    62.97     0.0       0.0       0.0
    STAGNANT WEDGE OR COUNTER FLOW SYSTEM IS EXPECTED IN THE FLOW AWAY REGION BASED ON JIRKA AND HARLEMAN. FH= 0.431
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     PLANT SITE NO.2 NEAR WASHBURN AT MISSOURI RIVER - CANAL WIDTH IS  60FT.          3 DEGREE F ISOTHERM PRINT OUT.

RUN # 2  LOAD =     2000.MEGA WATT              25.00000DEGREE F(DELTA T.)                1424.5CU FT/SEC(DISCHARGE)

FLOATING WARM WATER JETS --

FRD =  26.7      2H0/H0 = 30.0      V/U0 =  0.131      ANGLE = 90.0      DISC.DEP.=  2.000      AMB.TEMP= 58.000

E = 0.0500   CD = 1.0000   CF = 0.2000   RE = 0.218E 07   EV = 0.200E 00   EH = 0.200E-01   SUR.HT.EXC.CO.= 0.100E-04

     S         X         Y      TM      T       U           Q         HT        H         B       F        RI         3D.0   3D.DEP 3D.WID IHLF
   32.2       4.4      31.9   82.2 25.000 11.518     2849.00  35612.53   3.05      49.8 14.486   0.003    2671.91   4.44    72.5   0
   33.2       4.5      32.9   81.8 24.391 11.214     2920.10  35612.25   3.19      49.9 13.994   0.003    2733.46   4.62    72.3   3
   34.2       4.6      33.9   81.5 23.825 10.931     2989.42  35612.00   3.33      50.1 13.544   0.004    2793.55   4.80    72.1   3
   35.2       4.8      34.9   81.1 23.298 10.667     3057.11  35611.72   3.47      50.2 13.130   0.004    2851.91   4.97    71.9   3
   36.2       4.9      35.9   80.7 22.804 10.419     3123.27  35611.47   3.61      50.4 12.768   0.004    2908.66   5.15    71.8   3
   37.2       5.1      36.5   80.4 22.341 10.186     3188.03  35611.19   3.75      50.5 12.394   0.004    2963.91   5.32    71.6   3
   38.2       5.3      37.8   80.0 21.904  9.967     3251.48  35610.94   3.89      50.7 12.064   0.005    3017.74   5.48    71.5   3
   40.2       5.6      39.8   79.4 21.104  9.563     3374.79  35610.47   4.16      51.0 11.470   0.005    3121.57   5.81    71.2   2
   42.2       6.0      41.8   78.7 20.385  9.198     3493.79  35610.03   4.42      51.3 10.948   0.006    3220.55   6.12    71.0   2
   44.2       6.4      43.7   78.1 19.734  8.867     3608.96  35609.63   4.68      51.6 10.486   0.006    3315.29   6.42    70.8   2
   46.2       6.8      45.7   77.4 19.141  8.564     3720.70  35609.16   4.94      51.9 10.074   0.007    3406.15   6.72    70.7   2
   50.2       7.8      49.6   76.3 18.098  8.028     3935.14  35609.16   5.44      52.6  9.368   0.008    3577.47   7.29    70.5   1
   54.2       8.7      53.5   75.1 17.206  7.566     4139.23  35608.78   5.92      53.2  8.786   0.010    3738.55   7.82    70.5   1
   58.2       9.8      57.3   74.0 16.430  7.162     4334.55  35608.28   6.38      53.9  8.298   0.011    3884.93   8.33    70.3   1
   62.2      10.9      61.1   73.0 15.748  6.804     4522.29  35607.63   6.84      54.6  7.882   0.012    4023.80   8.80    70.3   1
   70.2      13.4      68.7   71.0 14.600  6.194     4878.57  35614.38   7.69      56.0  7.211   0.015    4276.88   9.68    70.4   0
   78.2      16.2      76.3   69.1 13.663  5.690     5213.61  35610.69   8.49      57.5  6.695   0.019    4501.17  10.45    70.7   0
   86.2      19.1      83.7   67.3 12.879  5.265     5531.10  35617.09   9.23      59.0  6.288   0.022    4700.69  11.14    71.2   0
   94.2      22.3      91.0   65.6 12.210  4.898     5833.70  35615.81   9.92      60.5  5.959   0.026    4878.45  11.75    71.7   0
  102.2      25.7      98.3   63.9 11.632  4.579     6123.34  35614.38  10.55      62.1  5.690   0.030    5036.88  12.29    72.3   0
  110.2      29.6     105.4   62.4 11.126  4.297     6401.54  35613.03  11.14      63.7  5.466   0.034    5177.97  12.76    72.9   0
  126.2      37.2     119.4   59.4 10.283  3.821     6928.31  35622.16  12.19      66.9  5.118   0.043    5415.52  13.53    74.3  -1
  142.2      45.6     132.9   56.8  9.601  3.435     7420.45  35623.53  13.07      70.2  4.866   0.052    5600.63  14.10    75.7  -1
  158.2      54.7     146.1   54.3  9.038  3.115     7883.09  35623.31  13.82      73.5  4.679   0.062    5742.55  14.52    77.2  -1
  174.2      64.3     158.9   52.0  8.563  2.846     8319.88  35620.84  14.46      76.9  4.539   0.072    5848.37  14.81    78.7  -1
  190.2      74.3     171.4   49.9  8.157  2.618     8733.76  35618.47  14.99      80.2  4.432   0.082    5926.29  14.99    80.2  -1
  206.2      84.9     183.4   48.0  7.804  2.421     9127.17  35616.09  15.44      83.5  4.351   0.093    5975.30  15.10    81.6  -1
  222.2      95.7     195.1   46.2  7.496  2.250     9502.11  35613.94  15.83      86.7  4.288   0.105    6005.59  15.14    83.0  -1
  238.2     107.0     206.5   44.6  7.223  2.101     9860.35  35611.78  16.15      89.9  4.241   0.116    6018.96  15.14    84.3  -1
  254.2     118.5     217.6   43.1  6.980  1.970    10203.39  35609.59  16.42      93.1  4.205   0.128    6017.08  15.09    85.5  -1
  270.2     130.3     228.4   41.7  6.761  1.854    10532.59  35607.38  16.66      96.2  4.178   0.139    6003.90  15.01    86.7  -1
  286.2     142.4     238.9   40.3  6.564  1.750    10849.16  35605.16  16.85      99.3  4.159   0.151    5979.77  14.91    87.8  -1
  302.2     154.7     249.1   39.1  6.384  1.658    11154.16  35602.96  17.02     102.3  4.145   0.163    5947.50  14.79    88.9  -1
  318.2     167.2     259.1   38.0  6.219  1.574    11448.57  35600.72  17.17     105.3  4.136   0.175    5908.03  14.66    89.9  -1
  334.2     179.9     268.8   36.9  6.068  1.499    11733.25  35598.47  17.29     108.2  4.131   0.187    5862.45  14.51    90.8  -1
  350.2     192.8     278.3   35.9  5.928  1.431    12008.99  35596.22  17.39     111.1  4.130   0.199    5811.69  14.35    91.7  -1
  366.2     205.8     287.6   35.0  5.799  1.369    12276.50  35593.97  17.48     113.9  4.131   0.212    5756.69  14.19    92.5  -1
  382.2     219.0     296.7   34.1  5.678  1.312    12536.43  35591.72  17.56     116.7  4.134   0.224    5697.50  14.03    93.2  -1
  398.2     232.1     305.5   33.3  5.565  1.260    12789.36  35589.41  17.63     119.4  4.139   0.236    5635.22  13.86    93.9  -1
  414.2     245.8     314.2   32.5  5.460  1.212    13035.03  35587.16  17.68     122.1  4.145   0.248    5570.10  13.68    94.5  -1
  430.2     259.1     322.7   31.7  5.361  1.167    13276.32  35584.88  17.73     124.7  4.153   0.261    5502.50  13.51    95.0  -1
  446.2     273.0     331.0   31.0  5.267  1.126    13511.28  35582.56  17.77     127.3  4.162   0.273    5432.71  13.33    95.5  -1
  462.2     286.8     339.2   30.3  5.179  1.088    13741.11  35580.25  17.81     129.9  4.171   0.285    5361.01  13.16    96.0  -1
  478.2     300.6     347.2   29.7  5.095  1.053    13966.20  35577.94  17.84     132.4  4.181   0.297    5287.59  12.98    96.4  -1
  494.2     314.5     355.1   29.1  5.015  1.019    14186.87  35575.63  17.87     134.9  4.192   0.310    5212.66  12.81    96.7  -1
  510.2     328.6     362.8   28.5  4.940  0.988    14403.46  35573.31  17.89     137.4  4.203   0.322    5136.33  12.64    97.0  -1
  526.2     342.7     370.4   28.0  4.867  0.959    14616.24  35571.00  17.91     139.8  4.215   0.334    5058.75  12.46    97.3  -1
  542.2     356.8     377.8   27.4  4.798  0.932    14825.48  35568.66  17.93     142.2  4.227   0.347    4980.01  12.29    97.5  -1
  558.2     371.1     385.1   26.9  4.732  0.906    15031.44  35566.31  17.95     144.6  4.240   0.359    4900.21  12.12    97.6  -1
  574.2     385.4     392.3   26.4  4.669  0.882    15234.34  35563.94  17.96     146.9  4.252   0.371    4819.41  11.95    97.7  -1
  590.2     399.7     399.4   26.0  4.608  0.859    15434.38  35561.59  17.98     149.2  4.265   0.384    4737.68  11.78    97.7  -1
  606.2     414.1     406.3   25.5  4.550  0.837    15631.77  35559.19  17.99     151.5  4.277   0.396    4655.07  11.61    97.7  -1
  622.2     428.6     413.2   25.1  4.493  0.816    15826.68  35556.78  18.00     153.7  4.290   0.409    4571.63  11.44    97.7  -1
  638.2     443.1     419.9   24.7  4.439  0.797    16019.30  35554.41  18.01     155.9  4.303   0.421    4487.37  11.27    97.6  -1
  654.2     457.7     426.5   24.3  4.386  0.778    16209.79  35552.00  18.02     158.1  4.316   0.434    4402.37  11.11    97.5  -1
  670.2     472.3     433.1   23.9  4.336  0.760    16398.27  35549.59  18.03     160.3  4.329   0.446    4316.54  10.94    97.3  -1
  686.2     486.9     439.5   23.5  4.287  0.743    16584.89  35547.19  18.04     162.4  4.342   0.459    4230.00  10.78    97.0  -1
  702.2     501.6     445.8   23.2  4.239  0.727    16769.80  35544.81  18.05     164.5  4.355   0.472    4142.76  10.61    96.7  -1
  718.2     516.3     452.1   22.8  4.193  0.712    16953.09  35542.38  18.06     166.6  4.368   0.484    4054.76  10.45    96.4  -1
  734.2     531.1     458.3   22.5  4.148  0.697    17134.80  35539.94  18.07     168.7  4.381   0.497    3966.07  10.28    96.0  -1
  750.2     545.9     464.3   22.2  4.105  0.683    17315.28  35537.53  18.07     170.7  4.394   0.510    3876.69  10.12    95.6  -1
  766.2     560.7     470.3   21.9  4.062  0.669    17494.41  35535.13  18.08     172.8  4.407   0.523    3786.60   9.96    95.1  -1
  782.2     575.6     476.2   21.6  4.021  0.656    17672.31  35532.69  18.09     174.8  4.419   0.535    3695.80   9.79    94.6  -1
  798.2     590.5     482.1   21.3  3.981  0.643    17849.11  35530.25  18.10     176.8  4.432   0.548    3604.30   9.63    94.0  -1
  814.2     605.4     487.8   21.0  3.942  0.631    18024.89  35527.84  18.11     178.7  4.445   0.561    3512.10   9.47    93.4  -1
  830.2     620.4     493.5   20.7  3.904  0.619    18199.69  35525.41  18.12     180.7  4.457   0.575    3419.20   9.30    92.7  -1
  846.2     635.3     499.2   20.4  3.867  0.608    18373.61  35523.00  18.13     182.6  4.470   0.588    3325.59   9.14    92.0  -1
  862.2     650.4     504.7   20.2  3.830  0.597    18546.72  35520.56  18.14     184.5  4.482   0.601    3231.25   8.97    91.2  -1
  878.2     665.4     510.2   19.9  3.795  0.587    18719.06  35518.13  18.16     186.4  4.496   0.614    3136.21   8.80    90.4  -1
  894.2     680.4     515.6   19.6  3.760  0.577    18890.72  35515.69  18.17     188.3  4.506   0.628    3040.43   8.63    89.5  -1
  910.2     695.5     520.9   19.4  3.726  0.567    19061.75  35513.20  18.18     190.2  4.518   0.641    2943.93   8.46    88.5  -1
  926.2     710.6     526.2   19.2  3.693  0.557    19232.20  35510.86  18.19     192.0  4.530   0.655    2846.66   8.29    87.5  -1
  942.2     725.7     531.4   18.9  3.660  0.548    19402.11  35508.38  18.21     193.9  4.542   0.668    2748.67   8.12    86.5  -1
  958.2     740.9     536.6   18.7  3.629  0.539    19571.53  35505.94  18.22     195.7  4.554   0.682    2649.97   7.95    85.3  -1
  974.2     756.1     541.7   18.5  3.597  0.531    19740.52  35503.47  18.23     197.5  4.566   0.696    2550.41   7.77    84.1  -1
  990.2     771.2     546.7   18.3  3.566  0.522    19909.11  35501.03  18.25     199.3  4.577   0.710    2450.14   7.59    82.9  -1
 1006.2     786.4     551.7   18.1  3.536  0.514    20077.34  35498.59  18.26     201.1  4.589   0.724    2349.10   7.41    81.5  -1
 1022.2     801.7     556.7   17.9  3.507  0.506    20245.25  35496.13  18.28     202.8  4.600   0.738    2247.28   7.22    80.1  -1
 1038.2     816.9     561.5   17.7  3.478  0.499    20412.89  35493.75  18.30     204.6  4.612   0.752    2144.67   7.03    78.6  -1
 1054.2     832.2     566.4   17.5  3.449  0.491    20580.27  35491.28  18.31     206.3  4.623   0.766    2041.26   6.84    77.1  -1
 1070.2     847.4     571.1   17.3  3.421  0.484    20747.41  35488.78  18.33     208.1  4.634   0.781    1937.04   6.64    75.4  -1
 1086.2     862.7     575.9   17.1  3.393  0.477    20914.38  35486.31  18.35     209.8  4.645   0.795    1832.01   6.44    73.6  -1
 1102.2     878.0     580.5   16.9  3.366  0.470    21081.22  35483.84  18.37     211.5  4.656   0.810    1726.16   6.23    71.8  -1
 1118.2     893.3     585.2   16.7  3.340  0.463    21248.05  35481.44  18.39     213.2  4.667   0.824    1619.40   6.02    69.8  -1
 1134.2     908.7     589.7   16.5  3.313  0.457    21414.88  35478.96  18.41     214.8  4.678   0.839    1511.74   5.80    67.7  -1
 1150.2     924.0     594.3   16.4  3.288  0.450    21581.77  35476.50  18.43     216.5  4.689   0.854    1403.16   5.58    65.5  -1
 1166.2     939.4     598.7   16.2  3.262  0.444    21748.72  35474.03  18.45     218.2  4.699   0.869    1293.65   5.34    63.1  -1
 1182.2     954.7     603.2   16.0  3.237  0.438    21915.77  35471.56  18.47     219.8  4.710   0.885    1183.19   5.09    60.6  -1
 1198.2     970.1     607.6   15.9  3.212  0.432    22082.91  35469.06  18.49     221.5  4.720   0.900    1071.80   4.84    57.9  -1
 1214.2     985.5     611.9   15.7  3.188  0.426    22250.17  35466.56  18.51     223.1  4.731   0.915     959.46   4.56    55.0  -1
 1230.2    1000.9     616.2   15.6  3.164  0.421    22417.55  35464.03  18.54     224.7  4.741   0.931     846.15   4.28    51.8  -1
 1246.2    1016.3     620.5   15.5  3.140  0.415    22585.08  35461.56  18.56     226.3  4.751   0.947     731.93   3.97    48.4  -1
 1262.2    1031.8     624.7   15.3  3.117  0.410    22752.77  35459.13  18.58     227.9  4.761   0.963     616.75   3.63    44.6  -1
 1278.2    1047.2     628.9   15.1  3.094  0.405    22920.61  35456.63  18.61     229.5  4.772   0.979     500.60   3.27    40.5  -1
 1294.2    1062.7     633.0   15.0  3.071  0.400    23088.66  35454.19  18.63     231.1  4.782   0.995     383.51   2.85    35.4  -1
 1310.2    1078.1     637.2   14.8  3.049  0.396    23256.89  35451.75  18.66     232.6  4.791   1.011     265.46   2.37    29.5  -1
 1326.2    1093.6     641.2   14.7  3.027  0.389    23425.33  35449.34  18.69     234.2  4.801   1.028     146.40   1.75    22.0  -1
 1342.2    1109.1     645.2   14.5  3.005  0.386    23593.96  35446.91  18.71     235.8  4.811   1.044      26.47   0.74     9.4  -1
 1358.2    1124.6     649.2   14.4  2.983  0.380    23762.77  35444.47  18.74     237.3  4.821   1.061       0.0    0.0     0.0  -1
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A R E A S  O F  E X C E S S  T E M P E R A T U R E  F O R         2000.0000        75.0000

TEMP.(F)        AREA (FT**2)

  1.25        6.567E 05  PARTIAL AREA - CALCULATION VALID TO  T = 2.983
  2.50        2.697E 05  PARTIAL AREA - CALCULATION VALID TO  T = 2.983
  3.75        1.128E 05
  5.00        4.776E 04
  6.25        2.545E 04
  7.50        1.606E 04
  8.75        1.135E 04
 10.00        8.514E 03
 11.25        6.579E 03
 12.50        5.314E 03
 13.75        4.363E 03
 15.00        3.666E 03
 16.25        3.143E 03
 17.50        2.705E 03
 18.75        2.368E 03
 20.00        2.066E 03
 21.25        1.810E 03
 22.50        1.586E 03
 23.75        1.369E 03
 25.00        9.661E 02
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     PLANT SITE NO.2 NEAR WASHBURN AT MISSOURI RIVER - CANAL WIDTH IS  60FT.          5 DEGREE F ISOTHERM PRINT OUT.
RUN # 2  LOAD =     2000.MEGA WATT              25.0000DEGREE F(DELTA T.)              1424.5CU FT/SEC(DISCHARGE)

FLOATING WARM WATER JETS --

FRD =  26.7     2BO/HO = 30.0     V/UO =  0.131     ANGLE = 90.0     DISC.DEP.=  2.000     AMB.TEMP= 58.000

E = 0.0500   CD = 1.0000   CF = 0.2000   RE = 0.218E 07   EV = 0.200E 00   EH = 0.200E-01   SUR.HT.EXC.CO.= 0.100E-04

    S        X        Y     TH      T       U          C         HT       H         B      F       RI        SD.G   SD.DEP SD.WID IHLF
   32.2     4.4     31.9  82.2 25.000 11.518    2849.60  35612.53   3.05     49.6 14.486  0.003    2465.91   3.87   63.2   0
   33.2     4.5     32.9  81.8 24.391 11.214    2920.10  35612.25   3.19     49.9 13.996  0.003    2515.36   4.02   62.9   3
   34.2     4.6     33.9  81.5 23.825 10.931    2989.42  35612.00   3.33     50.1 13.544  0.004    2562.69   4.17   62.6   3
   35.2     4.8     34.9  81.1 23.298 10.667    3057.11  35611.76   3.47     50.2 13.130  0.004    2608.58   4.31   62.3   3
   36.2     4.9     35.9  80.7 22.804 10.419    3123.27  35611.47   3.61     50.4 12.748  0.004    2652.57   4.45   62.1   3
   37.2     5.1     36.9  80.4 22.341 10.186    3188.03  35611.19   3.75     50.5 12.394  0.004    2694.97   4.59   61.8   3
   38.2     5.3     37.8  80.0 21.906  9.967    3251.48  35610.94   3.89     50.7 12.064  0.005    2735.86   4.72   61.6   3
   40.2     5.6     39.8  79.4 21.106  9.563    3374.79  35610.47   4.16     51.0 11.470  0.005    2813.49   4.99   61.2   2
   42.2     6.0     41.8  78.7 20.385  9.198    3493.79  35610.03   4.42     51.3 10.948  0.006    2886.06   5.24   60.8   2
   44.2     6.4     43.7  78.1 19.734  8.867    3608.96  35609.63   4.68     51.6 10.486  0.006    2954.03   5.48   60.5   2
   46.2     6.8     45.7  77.4 19.141  8.564    3720.70  35609.16   4.96     51.9 10.074  0.007    3017.82   5.72   60.1   2
   50.2     7.8     49.6  76.3 18.098  8.028    3935.16  35609.16   5.44     52.6  9.368  0.008    3134.16   6.16   59.6   1
   54.2     8.7     53.5  75.1 17.206  7.566    4139.23  35608.70   5.92     53.2  8.786  0.010    3237.24   6.58   59.2   1
   58.2     9.8     57.3  74.0 16.430  7.162    4334.55  35608.28   6.38     53.9  8.298  0.011    3328.72   6.96   58.8   1
   62.2    10.9     61.1  73.0 15.748  6.804    4522.29  35607.63   6.84     54.6  7.882  0.012    3409.87   7.32   58.5   1
   70.2    13.6     68.7  71.0 14.600  6.194    4878.57  35616.38   7.69     56.0  7.211  0.015    3545.64   7.96   58.0   0
   78.2    16.2     76.3  69.1 13.663  5.690    5213.61  35616.69   8.49     57.5  6.695  0.019    3650.45   8.51   57.6   0
   86.2    19.1     83.7  67.3 12.879  5.265    5531.10  35617.04   9.23     59.0  6.288  0.022    3729.06   8.98   57.3   0
   94.2    22.3     91.0  65.6 12.210  4.898    5833.70  35615.81   9.92     60.5  5.959  0.026    3785.05   9.37   57.2   0
  102.2    25.7     98.3  63.9 11.632  4.579    6123.34  35614.38  10.55     62.1  5.690  0.030    3821.45   9.70   57.0   0
  110.2    29.4    105.4  62.4 11.126  4.297    6401.94  35613.03  11.16     63.7  5.466  0.034    3840.73   9.97   56.9   0
  126.2    37.2    119.4  59.4 10.283  3.821    6928.31  35622.10  12.19     66.9  5.118  0.043    3837.27  10.35   56.8  -1
  142.2    45.6    132.9  56.6  9.601  3.435    7420.45  35623.53  13.07     70.2  4.866  0.052    3786.57  10.56   56.7  -1
  158.2    54.7    146.1  54.3  9.038  3.115    7883.09  35623.31  13.82     73.5  4.679  0.062    3699.81  10.64   56.6  -1
  174.2    64.3    158.9  52.0  8.563  2.846    8319.88  35620.86  14.46     76.9  4.539  0.072    3589.22  10.60   56.4  -1
  190.2    74.3    171.4  49.9  8.157  2.618    8733.76  35618.47  14.99     80.2  4.432  0.082    3449.70  10.49   56.1  -1
  206.2    84.9    183.6  48.0  7.806  2.421    9127.17  35616.09  15.44     83.5  4.351  0.093    3298.42  10.31   55.7  -1
  222.2    95.7    195.1  46.2  7.496  2.250    9502.11  35613.96  15.83     86.7  4.288  0.105    3135.50  10.07   55.2  -1
  238.2   107.0    206.5  44.6  7.223  2.101    9860.35  35611.78  16.15     89.9  4.241  0.116    2966.07   9.79   54.5  -1
  254.2   118.5    217.6  43.1  6.980  1.970   10203.39  35609.59  16.42     93.1  4.205  0.128    2786.57   9.49   53.6  -1
  270.2   130.3    228.4  41.7  6.761  1.856   10532.59  35607.38  16.66     96.2  4.178  0.139    2606.90   9.15   52.4  -1
  286.2   142.4    238.9  40.3  6.564  1.750   10849.16  35605.18  16.85     99.3  4.159  0.151    2420.45   8.79   51.1  -1
  302.2   154.7    249.1  39.1  6.384  1.658   11154.16  35602.96  17.02    102.3  4.145  0.163    2234.44   8.41   50.0  -1
  318.2   167.2    259.1  38.0  6.219  1.574   11448.57  35600.72  17.17    105.3  4.136  0.175    2047.58   8.02   49.2  -1
  334.2   179.9    268.8  36.9  6.068  1.499   11733.25  35598.47  17.29    108.2  4.131  0.187    1860.54   7.61   47.6  -1
  350.2   192.6    278.3  35.9  5.928  1.431   12008.95  35596.22  17.39    111.1  4.130  0.199    1673.75   7.18   45.9  -1
  366.2   205.8    287.6  35.0  5.799  1.369   12276.30  35593.97  17.48    113.9  4.131  0.212    1487.56   6.73   43.6  -1
  382.2   219.0    296.7  34.1  5.678  1.312   12536.43  35591.72  17.56    116.7  4.134  0.224    1302.19   6.26   41.6  -1
  398.2   232.3    305.5  33.3  5.565  1.260   12789.36  35589.41  17.63    119.4  4.139  0.236    1117.80   5.77   39.1  -1
  414.2   245.8    314.2  32.5  5.460  1.212   13035.63  35587.16  17.68    122.1  4.145  0.248     934.50   5.25   36.2  -1
  430.2   259.3    322.7  31.7  5.361  1.167   13276.32  35584.88  17.73    124.7  4.153  0.261     752.33   4.68   32.9  -1
  446.2   273.0    331.0  31.0  5.267  1.126   13511.21  35582.58  17.77    127.3  4.162  0.273     571.31   4.05   29.1  -1
  462.2   286.8    339.2  30.3  5.179  1.088   13741.11  35580.25  17.81    129.9  4.171  0.285     391.44   3.36   24.3  -1
  478.2   300.6    347.2  29.7  5.095  1.053   13966.20  35577.94  17.84    132.4  4.181  0.297     212.65   2.45   18.2  -1
  494.2   314.5    355.1  29.1  5.015  1.019   14186.67  35575.63  17.87    134.9  4.192  0.310      35.05   0.99    7.5  -1
  510.2   328.6    362.8  28.5  4.940  0.988   14403.40  35573.31  17.89    137.4  4.203  0.322        0.0    0.0    0.0  -1
  526.2   342.7    370.4  28.0  4.867  0.959   14616.24  35571.00  17.91    139.8  4.215  0.334        0.0    0.0    0.0  -1
  542.2   356.9    377.8  27.4  4.798  0.932   14825.40  35568.68  17.93    142.2  4.227  0.347        0.0    0.0    0.0  -1
  558.2   371.1    385.1  26.9  4.732  0.906   15031.44  35566.31  17.95    144.6  4.240  0.359        0.0    0.0    0.0  -1
  574.2   385.4    392.3  26.4  4.669  0.882   15234.36  35563.94  17.96    146.9  4.252  0.371        0.0    0.0    0.0  -1
  590.2   399.7    399.4  26.0  4.608  0.859   15434.38  35561.58  17.98    149.2  4.265  0.384        0.0    0.0    0.0  -1
  606.2   414.1    406.3  25.5  4.550  0.837   15631.77  35559.19  17.99    151.5  4.277  0.396        0.0    0.0    0.0  -1
  622.2   428.6    413.2  25.1  4.493  0.816   15826.08  35556.78  18.00    153.7  4.290  0.409        0.0    0.0    0.0  -1
  638.2   443.1    419.9  24.7  4.438  0.797   16018.30  35554.41  18.01    155.9  4.303  0.421        0.0    0.0    0.0  -1
  654.2   457.7    426.5  24.3  4.386  0.778   16208.70  35552.00  18.02    158.1  4.316  0.434        0.0    0.0    0.0  -1
  670.2   472.3    433.1  23.9  4.336  0.760   16396.27  35549.59  18.03    160.3  4.329  0.446        0.0    0.0    0.0  -1
  686.2   486.9    439.5  23.5  4.287  0.743   16584.84  35547.19  18.04    162.4  4.342  0.459        0.0    0.0    0.0  -1
  702.2   501.6    445.8  23.2  4.239  0.727   16768.80  35544.81  18.05    164.5  4.355  0.472        0.0    0.0    0.0  -1
  718.2   516.3    452.1  22.8  4.193  0.712   16953.09  35542.38  18.06    166.6  4.368  0.484        0.0    0.0    0.0  -1
  734.2   531.1    458.3  22.5  4.148  0.697   17134.88  35539.96  18.07    168.7  4.381  0.497        0.0    0.0    0.0  -1
  750.2   545.9    464.3  22.2  4.105  0.682   17315.26  35537.53  18.07    170.7  4.394  0.510        0.0    0.0    0.0  -1
  766.2   560.7    470.3  21.9  4.062  0.669   17494.41  35535.13  18.08    172.8  4.407  0.523        0.0    0.0    0.0  -1
  782.2   575.6    476.2  21.6  4.021  0.656   17672.31  35532.69  18.09    174.8  4.419  0.535        0.0    0.0    0.0  -1
  798.2   590.5    482.1  21.3  3.981  0.643   17849.11  35530.28  18.10    176.8  4.432  0.548        0.0    0.0    0.0  -1
  814.2   605.4    487.8  21.0  3.942  0.631   18024.84  35527.86  18.11    178.7  4.445  0.561        0.0    0.0    0.0  -1
  830.2   620.4    493.5  20.7  3.904  0.619   18199.49  35525.41  18.12    180.7  4.457  0.575        0.0    0.0    0.0  -1
  846.2   635.3    499.2  20.4  3.867  0.608   18373.01  35523.00  18.13    182.6  4.470  0.588        0.0    0.0    0.0  -1
  862.2   650.4    504.7  20.2  3.830  0.597   18546.72  35520.58  18.14    184.5  4.482  0.601        0.0    0.0    0.0  -1
  878.2   665.4    510.2  19.9  3.795  0.587   18718.08  35518.15  18.16    186.4  4.494  0.614        0.0    0.0    0.0  -1
  894.2   680.4    515.6  19.6  3.760  0.577   18890.72  35515.69  18.17    188.3  4.506  0.628        0.0    0.0    0.0  -1
  910.2   695.5    520.9  19.4  3.726  0.567   19061.75  35513.28  18.18    190.2  4.518  0.641        0.0    0.0    0.0  -1
  926.2   710.6    526.2  19.2  3.693  0.557   19232.20  35510.86  18.19    192.0  4.530  0.655        0.0    0.0    0.0  -1
  942.2   725.7    531.6  18.9  3.660  0.548   19402.11  35508.38  18.21    193.9  4.542  0.668        0.0    0.0    0.0  -1
  958.2   740.9    536.6  18.7  3.628  0.539   19571.53  35505.96  18.22    195.7  4.554  0.682        0.0    0.0    0.0  -1
  974.2   756.1    541.7  18.5  3.597  0.531   19740.52  35503.47  18.23    197.5  4.566  0.696        0.0    0.0    0.0  -1
  990.2   771.2    546.7  18.3  3.566  0.522   19909.11  35501.03  18.25    199.3  4.577  0.710        0.0    0.0    0.0  -1
 1006.2   786.4    551.7  18.1  3.536  0.514   20077.36  35498.59  18.26    201.1  4.589  0.724        0.0    0.0    0.0  -1
 1022.2   801.7    556.7  17.9  3.507  0.506   20245.25  35496.13  18.28    202.8  4.600  0.738        0.0    0.0    0.0  -1
 1038.2   816.9    561.5  17.7  3.478  0.499   20412.89  35493.75  18.30    204.6  4.612  0.752        0.0    0.0    0.0  -1
 1054.2   832.2    566.4  17.5  3.449  0.491   20580.27  35491.28  18.31    206.3  4.623  0.766        0.0    0.0    0.0  -1
 1070.2   847.4    571.1  17.3  3.421  0.484   20747.41  35488.78  18.33    208.1  4.634  0.781        0.0    0.0    0.0  -1
 1086.2   862.7    575.9  17.1  3.393  0.477   20914.38  35486.31  18.35    209.8  4.645  0.795        0.0    0.0    0.0  -1
 1102.2   878.0    580.5  16.9  3.366  0.470   21081.22  35483.84  18.37    211.5  4.656  0.810        0.0    0.0    0.0  -1
 1118.2   893.3    585.2  16.7  3.340  0.463   21248.05  35481.44  18.39    213.2  4.667  0.824        0.0    0.0    0.0  -1
 1134.2   908.7    589.7  16.5  3.313  0.457   21414.88  35478.94  18.41    214.8  4.678  0.839        0.0    0.0    0.0  -1
 1150.2   924.0    594.3  16.4  3.288  0.450   21581.77  35476.50  18.43    216.5  4.689  0.854        0.0    0.0    0.0  -1
 1166.2   939.4    598.7  16.2  3.262  0.444   21748.72  35474.03  18.45    218.2  4.699  0.869        0.0    0.0    0.0  -1
 1182.2   954.7    603.2  16.0  3.237  0.438   21915.77  35471.56  18.47    219.8  4.710  0.885        0.0    0.0    0.0  -1
 1198.2   970.1    607.6  15.9  3.212  0.432   22082.91  35469.06  18.49    221.5  4.720  0.900        0.0    0.0    0.0  -1
 1214.2   985.5    611.9  15.7  3.188  0.426   22250.17  35466.56  18.51    223.1  4.731  0.915        0.0    0.0    0.0  -1
 1230.2  1000.9    616.2  15.5  3.164  0.421   22417.55  35464.03  18.54    224.7  4.741  0.931        0.0    0.0    0.0  -1
 1246.2  1016.3    620.5  15.4  3.140  0.415   22585.08  35461.56  18.56    226.3  4.751  0.947        0.0    0.0    0.0  -1
 1262.2  1031.8    624.7  15.2  3.117  0.410   22752.77  35459.13  18.58    227.9  4.761  0.963        0.0    0.0    0.0  -1
 1278.2  1047.2    628.9  15.1  3.094  0.404   22920.61  35456.63  18.61    229.5  4.772  0.979        0.0    0.0    0.0  -1
 1294.2  1062.7    633.0  14.9  3.071  0.399   23088.66  35454.16  18.63    231.1  4.782  0.995        0.0    0.0    0.0  -1
 1310.2  1078.1    637.2  14.8  3.049  0.394   23256.88  35451.78  18.66    232.6  4.791  1.011        0.0    0.0    0.0  -1
 1326.2  1093.6    641.2  14.7  3.027  0.389   23425.33  35449.26  18.68    234.2  4.801  1.028        0.0    0.0    0.0  -1
 1342.2  1109.1    645.2  14.5  3.005  0.384   23593.96  35446.81  18.71    235.8  4.811  1.044        0.0    0.0    0.0  -1
 1358.2  1124.6    649.2  14.4  2.983  0.380   23762.77  35444.47  18.74    237.3  4.821  1.061        0.0    0.0    0.0  -1
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A R E A S  OF  E X C E S S   T E M P E R A T U R E   F O R          2000.0000      35.0000

TEMP.(F)      AREA (FT**2)

  1.25       4.5670E 05  PARTIAL AREA - CALCULATION VALID TO  T = 2.983
  2.50       2.0970E 05  PARTIAL AREA - CALCULATION VALID TO  T = 2.983
  3.75       1.1200E 05
  5.00       4.7300E 04
  6.25       2.5430E 04
  7.50       1.6060E 04
  8.75       1.1350E 04
 10.00       8.9140E 03
 11.25       6.5790E 03
 12.50       5.3140E 03
 13.75       4.3430E 03
 15.00       3.6860E 03
 16.25       3.1400E 03
 17.50       2.7090E 03
 18.75       2.3600E 03
 20.00       2.0640E 03
 21.25       1.8100E 03
 22.50       1.5860E 03
 23.75       1.3630E 03
 25.00       4.4411E 02
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     PLANT SITE NO.2 NEAR WASHBURN AT MISSOURI RIVER - CANAL WIDTH IS  60FT.        3 DEGREE F ISOTHERM PRINT OUT.
RUN # 4  LOAD =     2000.MEGA WATT                25.0000DEGREE F(DELTA T.)              1424.9CU FT/SEC(DISCHARGE)

FLOATING WARM WATER JETS --

FRD =    9.4     2B0/H0 = 15.0      V/U0 =  0.312      ANGLE = 90.0      DISC.DEP.=  4.000      AMB.TEMP= 58.000

E = 0.0900   CD = 1.0000   CF = 0.2000   RE = 0.218E 07   EV = 0.200E 00   EH = 0.203E-01   SUR.HT.EXC.CO.= 0.100E-04

      S         X         Y      TH      T        U         Q          HT        H         B       F       RI        3D.Q   3D.DEP  3D.WID IHLP
     58.2      14.6      54.9   70.5  25.000   4.992     2849.00   35612.53    5.19     56.1   5.791   0.026     2869.93   7.56     81.7   6
     59.2      19.8      55.8   70.0  24.664   4.892     2887.82   35612.34    5.31     56.3   5.702   0.027     2910.02   7.70     81.7   4
     60.2      20.1      56.8   69.5  24.342   4.795     2925.97   35612.25    5.42     56.4   5.619   0.028     2949.28   7.84     81.7   4
     61.2      20.5      57.7   69.0  24.034   4.702     2963.49   35612.06    5.53     56.6   5.540   0.030     2987.75   7.98     81.7   4
     62.2      20.8      58.7   68.5  23.738   4.611     3000.39   35611.91    5.64     56.8   5.465   0.031     3025.46   8.11     81.7   4
     63.2      21.2      59.6   68.1  23.454   4.527     3036.71   35611.72    5.74     57.0   5.394   0.032     3062.41   8.24     81.7   4
     64.2      21.6      60.5   67.6  23.181   4.444     3072.46   35611.53    5.85     57.2   5.327   0.033     3098.64   8.36     81.7   4
     66.2      22.4      62.4   66.7  22.665   4.287     3142.37   35611.22    6.05     57.5   5.202   0.036     3169.04   8.60     81.8   3
     68.2      23.2      64.2   65.8  22.186   4.140     3210.26   35610.91    6.24     57.9   5.090   0.039     3236.78   8.83     81.9   3
     70.2      24.0      66.0   65.0  21.738   4.002     3276.27   35610.59    6.43     58.3   4.987   0.041     3302.01   9.05     82.0   3
     72.2      24.9      67.8   64.2  21.320   3.873     3340.51   35610.25    6.61     58.6   4.894   0.044     3364.87   9.26     82.1   3
     76.2      26.7      71.4   62.6  20.559   3.636     3464.13   35609.78    6.95     59.4   4.730   0.050     3483.92   9.65     82.4   2
     80.2      28.5      74.9   61.1  19.883   3.425     3581.83   35609.25    7.27     60.2   4.592   0.056     3594.76  10.00     82.7   2
     84.2      30.5      78.4   59.7  19.278   3.236     3694.23   35608.75    7.57     60.9   4.475   0.063     3698.13  10.32     83.1   2
     88.2      32.6      81.8   58.4  18.732   3.066     3801.82   35608.22    7.84     61.7   4.375   0.069     3794.66  10.61     83.5   2
     96.2      36.9      88.5   55.9  17.785   2.766     4004.26   35608.22    8.33     63.3   4.216   0.083     3969.45  11.11     84.4   1
    104.2      41.5      95.1   53.7  16.989   2.516     4191.95   35607.75    8.76     64.8   4.093   0.097     4123.09  11.51     85.4   1
    112.2      46.4     101.4   51.6  16.307   2.302     4367.04   35607.13    9.10     66.4   4.001   0.112     4258.67  11.84     86.4   1
    120.2      51.5     107.6   49.7  15.716   2.119     4531.24   35606.25    9.41     68.0   3.930   0.127     4378.86  12.11     87.5   1
    136.2      62.1     119.5   46.4  14.739   1.820     4832.52   35612.97    9.90     71.1   3.834   0.159     4582.12  12.49     89.7   0
    152.2      73.5     130.8   43.6  13.955   1.588     5104.16   35614.81   10.26     74.2   3.779   0.193     4745.64  12.73     92.0   0
    168.2      85.5     141.6   41.1  13.308   1.403     5352.37   35614.72   10.54     77.2   3.750   0.227     4879.20  12.86     94.2   0
    184.2      97.6     151.9   39.0  12.760   1.252     5581.81   35612.94   10.74     80.1   3.738   0.262     4989.74  12.92     96.4   0
    200.2     110.2     161.7   37.0  12.288   1.128     5796.00   35611.06   10.90     83.0   3.737   0.297     5082.38  12.94     98.5   0
    216.2     123.1     171.2   35.3  11.874   1.023     5997.73   35609.25   11.02     85.8   3.744   0.333     5160.85  12.92    100.6   0
    232.2     136.3     180.2   33.8  11.506   0.934     6189.13   35607.53   11.11     88.5   3.756   0.369     5227.89  12.88    102.6   0
    248.2     149.7     189.0   32.4  11.176   0.857     6371.91   35605.81   11.18     91.2   3.773   0.406     5285.57  12.82    104.5   0
    280.2     177.0     205.5   30.0  10.602   0.731     6716.80   35604.72   11.28     96.3   3.812   0.480     5379.06  12.68    108.2  -1
    312.2     205.0     221.0   28.0  10.113   0.633     7040.95   35602.38   11.35    101.2   3.858   0.556     5449.93  12.52    111.6  -1
    344.2     233.5     235.6   26.2   9.687   0.554     7350.19   35599.67   11.41    105.9   3.905   0.633     5503.81  12.35    114.8  -1
    376.2     262.4     249.3   24.7   9.308   0.490     7648.62   35596.06   11.45    110.4   3.954   0.712     5546.27  12.18    117.5  -1
    408.2     291.7     262.3   23.3   8.966   0.436     7939.22   35592.53   11.49    114.8   4.002   0.792     5573.77  12.02    120.1  -1
    440.2     321.2     274.7   22.1   8.655   0.390     8224.39   35588.97   11.53    118.9   4.051   0.875     5593.96  11.87    122.4  -1
    472.2     351.0     286.4   21.0   8.367   0.351     8506.27   35585.47   11.57    123.0   4.098   0.960     5606.04  11.72    124.6  -1
    504.2     380.9     297.6   20.0   8.100   0.317     8786.11   35581.96   11.61    127.0   4.144   1.048     5610.76  11.58    126.5  -1
    536.2     411.1     308.3   19.1   7.850   0.287     9064.80   35578.47   11.66    130.8   4.189   1.138     5608.70  11.44    128.3  -1
    568.2     441.4     318.6   18.3   7.615   0.261     9343.08   35575.00   11.72    134.5   4.234   1.230     5600.29  11.31    129.8  -1
    600.2     471.9     328.4   17.5   7.394   0.238     9621.43   35571.53   11.77    138.1   4.277   1.326     5585.83  11.18    131.2  -1
    632.2     502.4     337.8   16.8   7.185   0.217     9900.35   35568.09   11.83    141.7   4.319   1.424     5565.56  11.06    132.4  -1
    664.2     533.1     346.9   16.2   6.987   0.198    10180.25   35564.63   11.90    145.2   4.361   1.525     5539.68  10.94    133.5  -1
    696.2     563.9     355.7   15.5   6.799   0.182    10461.36   35561.16   11.97    148.6   4.401   1.628     5508.10  10.82    134.4  -1
    728.2     594.8     364.1   15.0   6.619   0.167    10743.91   35557.72   12.04    151.9   4.441   1.735     5471.55  10.71    135.1  -1
    760.2     625.7     372.2   14.4   6.448   0.153    11028.21   35554.31   12.11    155.2   4.480   1.844     5429.49  10.59    135.7  -1
    792.2     656.7     380.0   13.9   6.286   0.141    11314.43   35550.91   12.19    158.4   4.518   1.957     5382.18  10.48    136.2  -1
    824.2     687.8     387.6   13.5   6.127   0.129    11602.68   35547.53   12.27    161.5   4.555   2.073     5329.88  10.37    136.5  -1
    856.2     719.0     395.0   13.0   5.977   0.119    11893.07   35544.19   12.35    164.6   4.592   2.191     5271.98  10.26    136.7  -1
    888.2     750.2     402.1   12.6   5.833   0.110    12185.67   35540.86   12.44    167.7   4.628   2.313     5209.14  10.14    136.7  -1
    920.2     781.4     408.9   12.2   5.695   0.101    12480.61   35537.53   12.52    170.7   4.664   2.438     5141.16  10.03    136.6  -1
    952.2     812.7     415.6   11.8   5.562   0.093    12778.01   35534.22   12.61    173.6   4.699   2.566     5068.01   9.91    136.4  -1
    984.2     844.1     422.1   11.5   5.436   0.086    13077.88   35530.94   12.71    176.5   4.733   2.697     4989.74   9.79    136.1  -1
   1016.2     875.5     428.3   11.1   5.310   0.079    13380.23   35527.66   12.80    179.4   4.767   2.832     4906.33   9.67    135.6  -1
   1048.2     906.9     434.4   10.8   5.192   0.073    13685.10   35524.44   12.90    182.3   4.800   2.969     4817.79   9.55    135.0  -1
   1080.2     938.3     440.4   10.5   5.077   0.067    13992.48   35521.25   12.99    185.1   4.833   3.110     4724.14   9.42    134.2  -1
   1112.2     969.8     446.1   10.2   4.967   0.061    14302.37   35518.06   13.09    187.8   4.865   3.254     4625.38   9.30    133.4  -1
   1144.2    1001.3     451.7    9.9   4.860   0.056    14614.80   35514.88   13.19    190.6   4.897   3.402     4521.44   9.16    132.4  -1
   1176.2    1032.8     457.2    9.7   4.757   0.052    14929.80   35511.72   13.29    193.3   4.928   3.552     4412.37   9.03    131.2  -1
   1208.2    1064.4     462.5    9.4   4.658   0.047    15247.36   35508.59   13.40    196.0   4.959   3.706     4298.18   8.89    130.0  -1
   1240.2    1096.0     467.6    9.2   4.562   0.043    15567.43   35505.50   13.50    198.6   4.990   3.863     4178.86   8.74    128.6  -1
   1272.2    1127.6     472.7    9.0   4.469   0.039    15890.00   35502.41   13.61    201.2   5.020   4.024     4054.40   8.59    127.0  -1
   1304.2    1159.2     477.6    8.7   4.379   0.036    16215.07   35499.36   13.71    203.8   5.050   4.188     3924.82   8.43    125.3  -1
   1336.2    1190.8     482.4    8.5   4.292   0.032    16542.66   35496.31   13.82    206.4   5.079   4.355     3790.16   8.27    123.5  -1
   1368.2    1222.5     487.1    8.3   4.207   0.029    16872.79   35493.28   13.93    209.0   5.108   4.525     3650.40   8.10    121.5  -1
   1400.2    1254.1     491.6    8.1   4.126   0.026    17205.47   35490.28   14.04    211.5   5.137   4.698     3505.56   7.92    119.4  -1
   1432.2    1285.8     496.1    7.9   4.047   0.024    17540.70   35487.28   14.15    214.0   5.165   4.875     3355.64   7.74    117.1  -1
   1464.2    1317.5     500.5    7.7   3.970   0.021    17878.48   35484.30   14.26    216.5   5.193   5.054     3200.64   7.55    114.6  -1
   1496.2    1349.1     504.7    7.6   3.896   0.019    18218.16   35481.41   14.37    218.9   5.221   5.237     3040.56   7.34    111.9  -1
   1528.2    1381.0     508.9    7.4   3.824   0.016    18560.73   35478.47   14.48    221.4   5.249   5.424     2875.36   7.13    109.0  -1
   1560.2    1412.7     513.0    7.2   3.754   0.014    18900.58   35475.59   14.59    223.8   5.276   5.613     2705.15   6.91    106.0  -1
   1592.2    1444.5     516.9    7.1   3.686   0.012    19248.62   35472.72   14.70    226.2   5.302   5.806     2529.92   6.67    102.7  -1
   1624.2    1476.2     520.8    6.9   3.620   0.010    19598.81   35469.88   14.81    228.6   5.329   6.001     2349.70   6.42     99.1  -1
   1656.2    1508.0     524.7    6.8   3.556   0.008    19945.09   35467.03   14.93    231.0   5.355   6.200     2164.52   6.16     95.3  -1
   1688.2    1539.8     528.4    6.6   3.494   0.007    20297.61   35464.22   15.04    233.3   5.381   6.402     1974.42   5.87     91.1  -1
   1720.2    1571.6     532.1    6.5   3.434   0.005    20651.71   35461.44   15.15    235.7   5.407   6.607     1779.42   5.57     86.6  -1
   1752.2    1603.4     535.7    6.4   3.376   0.004    21007.97   35458.66   15.27    238.0   5.433   6.815     1579.55   5.24     81.8  -1
   1784.2    1635.2     539.2    6.2   3.319   0.002    21366.12   35455.91   15.38    240.3   5.458   7.025     1374.85   4.89     76.4  -1
   1816.2    1667.0     542.6    6.1   3.264   0.001    21726.13   35453.16   15.49    242.6   5.483   7.239     1165.34   4.50     70.4  -1
   1848.2    1698.8     546.0    6.0   3.210  -0.000    22087.95   35450.47   15.61    244.9   5.508   7.456      951.07   4.06     63.7  -1
   1880.2    1730.6     549.3    5.9   3.158  -0.001    22451.56   35447.79   15.72    247.1   5.533   7.675      732.07   3.56     55.9  -1
   1912.2    1762.5     552.6    5.8   3.107  -0.002    22816.88   35445.09   15.83    249.4   5.557   7.897      508.35   2.96     46.7  -1
   1944.2    1794.3     555.8    5.7   3.058  -0.004    23181.91   35442.47   15.95    251.6   5.581   8.122      279.48   2.20     34.7  -1
   1976.2    1826.2     558.9    5.6   3.009  -0.005    23552.60   35439.86   16.06    253.8   5.605   8.350       46.96   0.90     14.2  -1
   2008.2    1858.3     562.0    5.5   2.961  -0.005    23922.92   35437.22   16.17    256.0   5.629   8.581        0.0    0.0      0.0  -1


      A R E A S   O F   E X C E S S   T E M P E R A T U R E   F O R            2000.0000        25.0000

  TEMP.(F)        AREA (FT**2)

     1.25         7.923E 05   PARTIAL AREA - CALCULATION VALID TO  T = 2.961
     2.50         5.599E 05   PARTIAL AREA - CALCULATION VALID TO  T = 2.961
     3.75         2.903E 05
     5.00         1.501E 05
     6.25         9.176E 04
     7.50         5.701E 04
     8.75         3.601E 04
    10.00         2.610E 04
    11.25         1.683E 04
    12.50         1.299E 04
    13.75         9.781E 03
    15.00         7.827E 03
    16.25         6.469E 03
    17.50         5.673E 03
    18.75         4.644E 03
    20.00         4.017E 03
    21.25         3.699E 03
    22.50         3.320E 03
    23.75         2.552E 03
    25.00         1.747E 03
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     PLANT SITE NO.2 NEAR WASHBURN AT MISSOURI RIVER - CANAL WIDTH IS  60FT.         5 DEGREE F ISOTHERM PRINT OUT.
RUN # 4  LOAD =     2000.MEGA WATT           25.0000DEGREE F(DELTA T.)              1424.5CU FT/SEC(DISCHARGE)

FLOATING WARM WATER JETS --

FRD =   9.6     ZBO/HO = 15.0     V/UO =  0.312     ANGLE = 90.0     DISC.DEP.=  4.000     AMB.TEMP= 56.000

F = 0.0500   CD = 1.0000   CF = 0.2000   AE = 0.216E 07   EV = 0.200E 00   EH = 0.200E-01   SUR.HT.EXC.CO.= 0.100E-04

     S        X        Y     TH      T       U          Q        HT       H        B      F      RI        5D.C  5D.DEP 5D.WID IHLF
   58.2     19.4     54.9  70.3 25.000   4.992     2849.00  35612.53   5.19     56.1  5.791  0.026    2542.50   6.59    71.1   0
   59.2     19.8     55.8  70.0 24.664   4.892     2887.02  35612.34   5.31     56.3  5.702  0.027    2570.29   6.70    71.1   4
   60.2     20.1     56.8  69.5 24.342   4.795     2925.97  35612.25   5.42     56.4  5.619  0.028    2597.25   6.82    71.0   4
   61.2     20.5     57.7  69.0 24.034   4.702     2963.49  35612.06   5.53     56.6  5.540  0.030    2623.41   6.93    70.9   4
   62.2     20.8     58.7  68.5 23.738   4.613     3000.39  35611.91   5.64     56.8  5.465  0.031    2648.86   7.03    70.9   4
   63.2     21.2     59.6  68.1 23.454   4.527     3036.71  35611.72   5.74     57.0  5.394  0.032    2673.65   7.14    70.8   4
   64.2     21.6     60.5  67.6 23.181   4.444     3072.46  35611.53   5.85     57.2  5.327  0.033    2697.38   7.24    70.8   4
   66.2     22.4     62.4  66.7 22.665   4.287     3142.37  35611.22   6.05     57.5  5.202  0.036    2743.21   7.44    70.7   3
   68.2     23.2     64.2  65.8 22.186   4.140     3210.26  35610.91   6.24     57.9  5.090  0.039    2786.45   7.62    70.7   3
   70.2     24.0     66.0  65.0 21.738   4.002     3276.27  35610.59   6.43     58.3  4.987  0.041    2827.26   7.80    70.6   3
   72.2     24.9     67.8  64.2 21.320   3.873     3340.51  35610.25   6.61     58.6  4.894  0.044    2865.66   7.96    70.6   3
   76.2     26.7     71.4  62.6 20.559   3.636     3464.13  35609.78   6.95     59.4  4.730  0.050    2936.60   8.27    70.6   2
   80.2     28.5     74.9  61.1 19.883   3.425     3581.83  35609.29   7.27     60.2  4.592  0.056    3000.22   8.56    70.7   2
   84.2     30.5     78.4  59.7 19.278   3.236     3694.22  35608.75   7.57     60.9  4.475  0.063    3056.98   8.79    70.8   2
   88.2     32.6     81.8  58.4 18.732   3.064     3801.87  35608.22   7.84     61.7  4.375  0.069    3107.79   9.01    70.9   2
   96.2     36.9     88.5  55.9 17.785   2.766     4004.26  35608.22   8.33     63.3  4.216  0.083    3194.08   9.38    71.3   1
  104.2     41.5     95.1  53.7 16.989   2.516     4191.95  35607.75   8.76     64.8  4.093  0.097    3263.20   9.67    71.7   1
  112.2     46.4    101.4  51.6 16.307   2.302     4367.04  35607.13   9.10     66.4  4.001  0.112    3316.40   9.86    72.2   1
  120.2     51.3    107.6  49.7 15.716   2.119     4531.24  35606.25   9.41     68.0  3.930  0.127    3362.23  10.07    72.8   1
  136.2     62.1    119.5  46.4 14.730   1.820     4832.52  35612.97   9.90     71.1  3.834  0.159    3424.22  10.29    73.9   0
  152.2     72.5    130.8  43.6 13.955   1.588     5104.16  35614.01  10.26     74.2  3.779  0.193    3460.19  10.40    75.1   0
  168.2     85.3    141.6  41.1 13.308   1.403     5352.37  35614.72  10.54     77.2  3.750  0.227    3478.03  10.42    76.4   0
  184.2     97.0    151.9  39.0 12.760   1.252     5581.81  35612.94  10.74     80.1  3.738  0.262    3482.86  10.40    77.5   0
  200.2    110.2    161.7  37.0 12.288   1.128     5796.00  35611.06  10.90     83.0  3.737  0.297    3478.23  10.33    78.7   0
  216.2    123.1    171.2  35.3 11.876   1.023     5997.73  35609.25  11.02     85.8  3.744  0.333    3466.53  10.26    79.8   0
  232.2    136.3    180.2  33.8 11.506   0.934     6189.13  35607.53  11.11     88.5  3.756  0.369    3449.38  10.16    80.8   0
  248.2    149.7    189.0  32.4 11.176   0.857     6371.91  35605.81  11.18     91.2  3.773  0.406    3427.94  10.03    81.8   0
  280.2    177.0    205.5  30.0 10.602   0.731     6716.60  35604.72  11.28     96.3  3.812  0.480    3379.55   9.78    83.5  -1
  312.2    205.0    221.0  28.0 10.113   0.633     7040.95  35602.38  11.35    101.2  3.858  0.556    3313.15   9.53    84.9  -1
  344.2    233.5    235.6  26.2  9.687   0.554     7350.19  35599.47  11.41    105.9  3.905  0.633    3243.07   9.28    86.1  -1
  376.2    262.4    249.3  24.7  9.308   0.490     7648.62  35596.06  11.45    110.4  3.954  0.712    3166.56   9.03    87.0  -1
  408.2    291.7    262.3  23.3  8.966   0.436     7939.22  35592.53  11.49    114.8  4.002  0.792    3084.38   8.78    87.7  -1
  440.2    321.2    274.7  22.1  8.655   0.390     8224.34  35588.97  11.53    118.9  4.051  0.875    2996.07   8.54    88.1  -1
  472.2    351.0    286.4  21.0  8.367   0.351     8504.27  35585.47  11.57    123.0  4.098  0.960    2904.10   8.30    88.3  -1
  504.2    380.9    297.6  20.0  8.100   0.317     8780.11  35581.96  11.61    127.0  4.146  1.048    2806.13   8.07    88.2  -1
  536.2    411.1    308.3  19.1  7.850   0.287     9064.60  35578.47  11.66    130.8  4.189  1.138    2703.04   7.83    87.8  -1
  568.2    441.6    318.6  18.3  7.615   0.261     9343.06  35575.00  11.72    134.5  4.234  1.230    2594.61   7.60    87.2  -1
  600.2    471.5    328.4  17.5  7.394   0.238     9621.43  35571.53  11.77    138.1  4.277  1.326    2481.46   7.38    86.4  -1
  632.2    502.4    337.8  16.8  7.185   0.217     9900.39  35568.09  11.83    141.7  4.319  1.424    2362.95   7.13    85.3  -1
  664.2    533.1    346.9  16.2  6.987   0.198    10180.25  35564.63  11.90    145.2  4.361  1.525    2234.24   6.88    84.0  -1
  696.2    563.9    355.7  15.5  6.799   0.182    10461.34  35561.16  11.97    148.6  4.401  1.628    2110.30   6.63    82.4  -1
  728.2    594.8    364.1  15.0  6.619   0.167    10743.91  35557.72  12.04    151.9  4.441  1.735    1976.09   6.36    80.4  -1
  760.2    625.7    372.2  14.4  6.448   0.153    11028.21  35554.31  12.11    155.2  4.480  1.844    1830.95   6.11    78.2  -1
  792.2    656.7    380.0  13.9  6.284   0.141    11314.43  35550.91  12.19    158.4  4.518  1.957    1691.62   5.83    75.7  -1
  824.2    687.8    387.6  13.5  6.127   0.129    11602.60  35547.53  12.27    161.5  4.555  2.073    1541.26   5.53    72.6  -1
  856.2    719.0    395.0  13.0  5.977   0.119    11893.07  35544.19  12.35    164.6  4.592  2.191    1389.46   5.22    69.6  -1
  888.2    750.2    402.1  12.6  5.833   0.110    12185.67  35540.84  12.44    167.7  4.628  2.313    1224.20   4.88    65.6  -1
  920.2    781.4    408.9  12.2  5.695   0.101    12480.61  35537.53  12.52    170.7  4.664  2.438    1017.38   4.52    61.6  -1
  952.2    812.7    415.6  11.8  5.562   0.093    12776.61  35534.22  12.61    173.6  4.699  2.566     886.94   4.12    56.7  -1
  984.2    844.1    422.1  11.5  5.434   0.086    13077.00  35530.94  12.71    176.5  4.733  2.697     706.90   3.64    50.6  -1
 1016.2    875.5    428.3  11.1  5.310   0.079    13380.23  35527.66  12.80    179.4  4.767  2.832     523.20   3.14    44.0  -1
 1048.2    906.9    434.4  10.8  5.192   0.073    13685.10  35524.44  12.90    182.1  4.800  2.969     333.87   2.50    35.6  -1
 1080.2    938.3    440.4  10.5  5.077   0.067    13992.40  35521.25  12.99    185.1  4.833  3.110     138.88   1.61    22.9  -1
 1112.2    969.8    446.1  10.2  4.967   0.061    14302.37  35518.06  13.09    187.8  4.865  3.256       0.0    0.0     0.0  -1
 1144.2   1001.3    451.7   9.9  4.860   0.056    14614.80  35514.88  13.19    190.6  4.897  3.402       0.0    0.0     0.0  -1
 1176.2   1032.8    457.2   9.7  4.757   0.052    14929.80  35511.72  13.29    193.3  4.928  3.552       0.0    0.0     0.0  -1
 1208.2   1064.4    462.5   9.4  4.658   0.047    15247.38  35508.59  13.40    196.0  4.9 9  3.706       0.0    0.0     0.0  -1
 1240.2   1096.0    467.6   9.2  4.562   0.043    15567.43  35505.50  13.50    198.6  4.990  3.863       0.0    0.0     0.0  -1
 1272.2   1127.6    472.7   8.9  4.469   0.034    15890.00  35502.41  13.61    201.2  5.020  4.024       0.0    0.0     0.0  -1
 1304.2   1158.2    477.6   8.7  4.379   0.036    16215.62  35499.34  13.71    203.8  5.050  4.188       0.0    0.0     0.0  -1
 1336.2   1190.0    482.4   8.5  4.292   0.032    16542.46  35496.31  13.82    206.4  5.074  4.355       0.0    0.0     0.0  -1
 1368.2   1222.5    487.1   8.3  4.207   0.029    16872.29  35493.28  13.93    209.0  5.108  4.525       0.0    0.0     0.0  -1
 1400.2   1254.1    491.6   8.1  4.126   0.026    17204.47  35490.28  14.04    211.5  5.137  4.698       0.0    0.0     0.0  -1
 1432.2   1285.9    496.1   7.9  4.047   0.024    17538.96  35487.28  14.15    214.0  5.165  4.875       0.0    0.0     0.0  -1
 1464.2   1317.5    500.5   7.7  3.970   0.021    17875.86  35484.34  14.26    216.5  5.193  5.054       0.0    0.0     0.0  -1
 1496.2   1349.3    504.7   7.6  3.896   0.019    18215.14  35481.41  14.37    218.9  5.221  5.237       0.0    0.0     0.0  -1
 1528.2   1381.0    508.9   7.4  3.824   0.016    18556.73  35478.47  14.48    221.4  5.248  5.424       0.0    0.0     0.0  -1
 1560.2   1412.7    513.0   7.2  3.754   0.014    18900.54  35475.56  14.59    223.8  5.276  5.613       0.0    0.0     0.0  -1
 1592.2   1444.5    516.9   7.1  3.686   0.012    19246.62  35472.72  14.70    226.2  5.302  5.806       0.0    0.0     0.0  -1
 1624.2   1476.2    520.8   6.9  3.620   0.010    19594.61  35469.88  14.81    228.6  5.329  6.001       0.0    0.0     0.0  -1
 1656.2   1508.0    524.7   6.8  3.556   0.009    19945.09  35467.03  14.93    231.0  5.355  6.200       0.0    0.0     0.0  -1
 1688.2   1539.8    528.4   6.6  3.494   0.007    20297.41  35464.22  15.04    233.3  5.381  6.402       0.0    0.0     0.0  -1
 1720.2   1571.6    532.1   6.5  3.434   0.005    20651.71  35461.44  15.15    235.7  5.407  6.607       0.0    0.0     0.0  -1
 1752.2   1603.4    535.7   6.4  3.376   0.004    21007.97  35458.66  15.27    238.0  5.433  6.815       0.0    0.0     0.0  -1
 1784.2   1635.2    539.2   6.2  3.319   0.002    21366.12  35455.91  15.38    240.3  5.458  7.025       0.0    0.0     0.0  -1
 1816.2   1667.0    542.6   6.1  3.264   0.001    21726.13  35453.16  15.49    242.6  5.483  7.238       0.0    0.0     0.0  -1
 1848.2   1698.8    546.0   6.0  3.210  -0.000    22087.99  35450.47  15.61    244.9  5.508  7.456       0.0    0.0     0.0  -1
 1880.2   1730.6    549.3   5.9  3.158  -0.001    22451.56  35447.79  15.72    247.1  5.533  7.675       0.0    0.0     0.0  -1
 1912.2   1762.5    552.6   5.8  3.107  -0.002    22816.88  35445.09  15.83    249.4  5.557  7.897       0.0    0.0     0.0  -1
 1944.2   1794.3    555.8   5.7  3.058  -0.004    23183.91  35442.47  15.95    251.6  5.581  8.122       0.0    0.0     0.0  -1
 1976.2   1826.2    558.9   5.6  3.009  -0.005    23552.60  35439.84  16.06    253.8  5.605  8.350       0.0    0.0     0.0  -1
 2008.2   1858.0    562.0   5.5  2.963  -0.005    23922.43  35437.22  16.17    256.0  5.629  8.581       0.0    0.0     0.0  -1
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     AREAS OF EXCESS TEMPERATURE FOR              2000.0000        25.0000

  TEMP.(F)        AREA (FT**2)

     1.25       7.923E 05   PARTIAL AREA - CALCULATION VALID TO   T = 2.963
     2.50       5.394E 05   PARTIAL AREA - CALCULATION VALID TO   T = 2.963
     3.75       2.403E 05
     5.00       1.601E 05
     6.25       9.376E 04
     7.50       5.703E 04
     8.75       3.603E 04
    10.00       2.410E 04
    11.25       1.693E 04
    12.50       1.255E 04
    13.75       9.793E 03
    15.00       7.827E 03
    16.25       6.409E 03
    17.50       5.673E 03
    18.75       4.844E C3
    20.00       4.017E 03
    21.25       3.498E 03
    22.50       3.020E 03
    23.75       2.592E 03
    25.00       1.747E 03
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     PLANT SITE NO.2 NEAR WASHBURN AT MISSOURI RIVER - CANAL WIDTH IS  60FT.          3 DEGREE F ISOTHERM PRINT OUT.

RUN # 6  LOAD =      2000.MEGA WATT              25.0000DEGREE F(DELTA T.)            1424.9CU FT/SEC(DISCHARGE)

FLOATING WARM WATER JETS --

FRD =    4.6     2B0/H0 =  9.2     V/U0 =  0.556     ANGLE = 90.0     DISC.DEP.=  6.900     AMB.TEMP= 58.030

E = 0.0500   CD = 1.0000   CF = 0.2000   RE = 0.218E 07   EV = 0.200E 00   EH = 0.200E-01   SUR.HT.EXC.CO.= 0.100E-04

      S         X         Y     TH      T        U          Q          HT       H         R       F        RI       3D.Q   3D.DEP 3D.WID INLP
    88.2      51.8      71.4   54.0 25.000   2.079     2849.00   35612.50   5.93      68.5   3.886   0.118    3278.91   8.63    99.8   0
    91.5      53.8      74.0   52.6 24.343   1.939     2925.84   35612.09   6.12      69.1   3.823   0.131    3360.29   8.86   100.0   3
    94.7      55.8      76.5   51.3 23.752   1.814     2998.61   35611.75   6.30      69.6   3.770   0.144    3450.84   9.06   100.2   3
    98.0      57.9      79.1   50.1 23.217   1.701     3067.74   35611.41   6.46      70.2   3.724   0.157    3527.43   9.24   100.4   3
   101.2      60.0      81.5   48.9 22.728   1.599     3133.62   35611.03   6.61      70.8   3.689   0.171    3598.65   9.40   100.7   3
   104.5      62.1      84.0   47.9 22.281   1.507     3196.58   35610.66   6.74      71.3   3.657   0.185    3665.07   9.55   101.0   3
   107.7      64.3      86.3   46.8 21.869   1.422     3256.88   35610.31   6.87      71.9   3.630   0.199    3727.17   9.68   101.3   3
   114.2      68.9      91.0   45.0 21.130   1.273     3370.52   35609.78   7.09      73.0   3.589   0.227    3840.06   9.91   102.0   2
   120.7      73.5      95.5   43.3 20.488   1.147     3476.16   35609.19   7.28      74.1   3.559   0.256    3940.14  10.09   102.7   2
   127.2      78.3      99.9   41.8 19.920   1.038     3575.10   35608.63   7.44      75.2   3.539   0.285    4029.63  10.24   103.4   2
   133.7      83.2     104.2   40.4 19.416   0.943     3668.35   35607.97   7.58      76.3   3.529   0.314    4110.22  10.36   104.2   2
   146.7      93.3     112.6   37.9 18.542   0.786     3840.89   35608.75   7.81      78.4   3.513   0.372    4290.12  10.54   105.8   1
   159.7     103.7     120.2   35.8 17.810   0.662     3998.76   35608.50   7.99      80.5   3.514   0.430    4367.87  10.66   107.5   1
   172.7     114.4     127.6   33.9 17.179   0.561     4145.41   35607.78   8.13      82.6   3.524   0.488    4468.92  10.74   109.1   1
   185.7     125.3     134.7   32.3 16.626   0.478     4283.26   35606.59   8.26      84.6   3.540   0.545    4557.03  10.78   110.7   1
   211.7     147.6     148.0   29.5 15.695   0.349     4538.79   35617.50   8.40      88.6   3.583   0.656    4705.14  10.81   113.9   0
   237.7     170.5     160.3   27.2 14.916   0.254     4776.06   35619.91   8.52      92.3   3.633   0.765    4825.46  10.79   116.9   0
   263.7     193.8     171.8   25.3 14.245   0.182     5001.18   35619.69   8.61      96.0   3.686   0.872    4926.40  10.75   119.8   0
   289.7     217.5     182.6   23.6 13.651   0.125     5218.27   35616.88   8.69      99.5   3.742   0.977    5012.89  10.69   122.6   0
   315.7     241.6     192.7   22.2 13.117   0.080     5430.09   35613.96   8.75     102.9   3.797   1.080    5088.31  10.63   124.9   0
   341.7     265.6     202.2   20.9 12.632   0.043     5638.34   35611.31   8.82     106.1   3.852   1.181    5154.73  10.57   127.1   0
   393.7     314.6     219.7   18.7 11.781  -0.010     6047.02   35621.44   8.93     112.4   3.960   1.380    5266.94  10.45   131.5  -1
   445.7     364.1     235.6   17.0 11.033  -0.049     6457.04   35619.06   9.06     118.3   4.065   1.579    5355.63  10.36   135.1  -1
   497.7     414.0     250.1   15.5 10.367  -0.076     6871.03   35616.75   9.19     124.0   4.165   1.779    5425.12  10.26   138.1  -1
   549.7     464.3     263.6   14.2  9.767  -0.095     7291.89   35611.18   9.34     129.6   4.261   1.981    5477.03  10.15   140.6  -1
   601.7     514.8     275.7   13.1  9.222  -0.110     7721.60   35605.88   9.50     134.6   4.354   2.188    5512.76  10.06   142.7  -1
   653.7     565.6     287.0   12.1  8.725  -0.120     8160.80   35601.25   9.66     139.7   4.443   2.399    5532.89   9.98   144.3  -1
   705.7     616.5     297.6   11.3  8.268  -0.127     8610.50   35597.06   9.84     144.6   4.529   2.616    5537.66   9.90   145.3  -1
   757.7     667.6     307.4   10.5  7.848  -0.132     9071.04   35593.22  10.02     149.3   4.612   2.839    5526.98   9.83   146.6  -1
   809.7     718.7     316.6    9.8  7.459  -0.135     9542.43   35589.41  10.21     153.9   4.693   3.069    5500.79   9.75   146.9  -1
   861.7     770.0     325.2    9.2  7.100  -0.137    10024.67   35585.59  10.41     158.4   4.771   3.306    5458.95   9.66   147.0  -1
   913.7     821.4     333.3    8.7  6.766  -0.138    10517.91   35581.78  10.61     162.8   4.846   3.550    5401.31   9.57   146.8  -1
   965.7     872.8     340.9    8.2  6.457  -0.138    11029.69   35578.06  10.82     167.1   4.920   3.802    5327.83   9.47   146.3  -1
  1017.7     924.3     348.1    7.7  6.169  -0.138    11538.26   35574.41  11.03     171.3   4.991   4.061    5238.44   9.36   145.5  -1
  1069.7     975.9     354.9    7.3  5.901  -0.137    12055.63   35570.81  11.24     175.5   5.060   4.328    5133.05   9.25   144.3  -1
  1121.7    1027.5     361.4    6.9  5.651  -0.135    12587.16   35567.31  11.46     179.5   5.128   4.601    5011.69   9.12   142.9  -1
  1173.7    1079.1     367.5    6.6  5.418  -0.134    13127.12   35563.91  11.68     183.5   5.194   4.882    4874.42   8.98   141.1  -1
  1225.7    1130.8     373.3    6.3  5.201  -0.132    13679.06   35560.56  11.90     187.5   5.258   5.170    4721.37   8.82   139.1  -1
  1277.7    1182.5     378.9    6.0  4.997  -0.130    14230.47   35557.28  12.12     191.4   5.321   5.464    4552.66   8.66   136.7  -1
  1329.7    1234.2     384.2    5.7  4.807  -0.129    14792.88   35554.03  12.34     195.2   5.382   5.765    4368.47   8.47   134.0  -1
  1381.7    1286.0     389.2    5.5  4.628  -0.127    15361.89   35550.88  12.56     199.0   5.442   6.072    4168.97   8.27   131.0  -1
  1433.7    1337.7     394.1    5.2  4.461  -0.126    15937.13   35547.75  12.77     202.7   5.500   6.385    3954.35   8.05   127.7  -1
  1485.7    1389.5     398.7    5.0  4.304  -0.122    16518.26   35544.69  12.99     206.4   5.557   6.703    3724.81   7.81   124.0  -1
  1537.7    1441.3     403.2    4.8  4.156  -0.120    17104.96   35541.63  13.21     210.0   5.613   7.028    3480.58   7.54   119.9  -1
  1589.7    1493.2     407.5    4.6  4.016  -0.118    17696.94   35538.69  13.43     213.6   5.668   7.357    3221.85   7.25   115.4  -1
  1641.7    1545.0     411.6    4.5  3.885  -0.116    18293.95   35535.75  13.64     217.1   5.722   7.693    2948.86   6.94   110.4  -1
  1693.7    1596.9     415.6    4.3  3.761  -0.114    18895.76   35532.88  13.86     220.6   5.776   8.033    2661.80   6.59   104.9  -1
  1745.7    1648.7     419.4    4.1  3.644  -0.112    19502.11   35530.03  14.07     224.1   5.826   8.378    2360.90   6.20    98.8  -1
  1797.7    1700.6     423.1    4.0  3.533  -0.110    20112.86   35527.25  14.28     227.6   5.877   8.727    2046.17   5.77    92.0  -1
  1849.7    1752.5     426.6    3.9  3.428  -0.109    20727.73   35524.47  14.49     231.0   5.926   9.082    1718.43   5.29    84.3  -1
  1901.7    1804.3     430.1    3.7  3.328  -0.107    21346.88   35521.78  14.70     234.3   5.975   9.440    1377.29   4.74    75.5  -1
  1953.7    1856.2     433.4    3.6  3.234  -0.105    21969.60   35519.09  14.91     237.7   6.023   9.803    1023.15   4.08    65.1  -1
  2005.7    1908.1     436.7    3.5  3.144  -0.103    22595.85   35516.44  15.11     241.0   6.070  10.170     656.20   3.27    52.1  -1
  2057.7    1960.0     439.8    3.4  3.058  -0.102    23225.85   35513.86  15.32     244.3   6.117  10.541     278.67   2.12    33.8  -1
  2109.7    2011.9     442.8    3.3  2.977  -0.100    23859.24   35511.31  15.52     247.5   6.163  10.916       0.0   0.0      0.0  -1


     AREAS OF EXCESS TEMPERATURE FOR              2000.3000       25.0300


   TEMP.(F)        AREA (FT**2)

     1.25         8.454E 05   PARTIAL AREA - CALCULATION VALID TO  T = 2.977
     2.50         5.964E 05   PARTIAL AREA - CALCULATION VALID TO  T = 2.977
     3.75         3.527E 05
     5.00         2.197E 05
     6.25         1.477E 05
     7.50         1.015E 05
     8.75         7.180E 04
    10.00         5.156E 04
    11.25         3.775E 04
    12.50         2.829E 04
    13.75         2.394E 04
    15.00         1.837E 04
    16.25         1.290E 04
    17.50         1.033E 04
    18.75         8.471E 03
    20.00         7.064E 03
    21.25         5.964E 03
    22.50         5.039E 03
    23.75         4.141E 03
    25.00         2.647E 03
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PLANT SITE NO.2 NEAR WASHBURN AT MISSOURI RIVER - CANAL WIDTH IS  60FT.        5 DEGREE F ISOTHERM PRINT OUT.
RUN # 6  LOAD =    2000.MEGA WATT            25.00000EGREE F(DELTA T.)         1424.5CU FT/SEC(DISCHARGE)

FLOATING WARM WATER JETS --

FRO =   4.6     ZRO/HO =  9.2     V/UO =  0.556     ANGLE = 90.0     DISC.DEP.=  6.500     AMB.TEMP= 58.000

E = 0.0500   CD = 1.0000   CF = 0.2000   RE = 0.216E 07   EV = 0.200E 03   EH = 0.200E-01   SUR.HT.EXC.CO.= 0.100E-04

     S        X        Y      TH      T       U          Q          HT       H         B       F       RI       5D.L    5D.DEP  5D.WID IHLF
    88.2     51.8     71.4   54.0  25.000   2.079     2849.00   35612.50   5.93     68.5   3.880   0.118   2700.36   7.52     86.9   2
    91.5     53.8     74.0   52.6  24.343   1.939     2925.06   35612.09   6.12     69.1   3.826   0.131   2751.96   7.70     86.8   2
    94.7     55.6     76.5   51.3  23.752   1.814     2998.61   35611.75   6.30     69.6   3.770   0.144   2796.44   7.86     86.9   2
    98.0     57.4     79.1   50.1  23.217   1.701     3067.74   35611.41   6.46     70.2   3.726   0.157   2840.90   8.00     87.0   2
   101.2     60.0     81.5   48.9  22.728   1.599     3133.62   35611.03   6.61     70.8   3.689   0.171   2878.67   8.13     87.1   2
   104.5     62.1     84.0   47.9  22.281   1.507     3196.56   35610.66   6.74     71.3   3.657   0.185   2913.42   8.24     87.2   2
   107.7     64.3     86.3   46.8  21.868   1.422     3256.88   35610.31   6.87     71.8   3.630   0.199   2945.14   8.34     87.3   2
   114.2     68.4     91.0   45.0  21.130   1.273     3370.52   35609.78   7.09     73.0   3.589   0.227   3000.06   8.51     87.6   2
   120.7     73.5     95.5   43.3  20.488   1.147     3476.16   35609.19   7.28     74.1   3.559   0.256   3047.97   8.65     88.0   2
   127.2     78.3     99.9   41.8  19.920   1.038     3575.10   35608.63   7.44     75.2   3.539   0.285   3088.19   8.75     88.4   2
   133.7     83.2    104.2   40.6  19.414   0.943     3668.35   35607.97   7.58     76.3   3.525   0.316   3122.77   8.82     88.8   2
   146.7     93.3    112.4   37.9  18.542   0.786     3840.09   35606.75   7.81     78.6   3.513   0.372   3176.83   8.94     89.8   1
   159.7    103.7    120.2   35.6  17.810   0.662     3998.76   35606.50   7.99     80.5   3.516   0.430   3221.57   9.00     90.8   1
   172.7    114.6    127.6   33.9  17.179   0.561     4145.61   35607.76   8.13     82.6   3.526   0.488   3254.60   9.03     91.6   1
   185.7    125.3    134.7   32.3  16.626   0.478     4283.26   35608.59   8.24     84.6   3.540   0.545   3280.20   9.03     92.6   1
   211.7    147.6    148.0   29.5  15.695   0.349     4538.79   35617.90   8.40     88.6   3.583   0.656   3316.67   8.99     94.1   0
   237.7    170.5    160.3   27.2  14.916   0.256     4776.06   35619.41   8.52     92.3   3.633   0.765   3337.46   8.91     96.5   0
   263.7    193.6    171.8   25.3  14.245   0.182     5001.18   35619.09   8.61     96.0   3.686   0.872   3347.36   8.81     98.2   0
   289.7    217.4    182.6   23.6  13.651   0.125     5216.27   35616.88   8.69     99.5   3.742   0.977   3348.04   8.70     99.7   0
   315.7    241.4    192.7   22.2  13.117   0.080     5430.09   35613.96   8.75    102.9   3.797   1.080   3343.59   8.60    101.0   0
   341.7    265.6    202.2   20.9  12.632   0.043     5630.34   35611.31   8.82    106.1   3.856   1.181   3332.61   8.49    102.2   0
   393.7    314.6    219.7   18.7  11.781  -0.010     6047.02   35621.46   8.92    112.4   3.960   1.380   3297.71   8.27    104.1  -1
   445.7    364.1    235.6   17.0  11.033  -0.049     6457.04   35615.06   9.06    118.3   4.065   1.579   3243.24   8.06    105.3  -1
   497.7    414.0    250.1   15.5  10.367  -0.076     6871.03   35610.75   9.19    124.0   4.165   1.779   3171.73   7.85    105.9  -1
   549.7    464.3    263.4   14.2   9.767  -0.095     7291.09   35611.38   9.36    129.4   4.261   1.981   3083.03   7.64    105.9  -1
   601.7    514.8    275.7   13.1   9.222  -0.110     7721.60   35605.88   9.50    134.6   4.356   2.186   2977.62   7.43    105.4  -1
   653.7    565.6    287.0   12.1   8.725  -0.120     8160.80   35601.29   9.66    139.7   4.443   2.399   2856.98   7.21    104.2  -1
   705.7    616.5    297.6   11.3   8.268  -0.127     8610.50   35597.08   9.84    144.8   4.529   2.616   2719.30   6.98    102.8  -1
   757.7    667.6    307.6   10.5   7.848  -0.132     9071.64   35593.22  10.02    149.3   4.612   2.836   2558.67   6.73    100.2  -1
   809.7    718.7    316.8    9.8   7.459  -0.135     9542.43   35589.61  10.21    153.9   4.693   3.069   2363.04   6.48     97.3  -1
   861.7    770.0    325.2    9.2   7.100  -0.137    10026.67   35585.99  10.41    158.4   4.771   3.306   2189.40   6.16     93.6  -1
   913.7    821.4    333.3    8.7   6.766  -0.138    10517.51   35581.76  10.61    162.8   4.846   3.550   1976.75   5.84     89.5  -1
   965.7    872.8    340.9    8.2   6.457  -0.138    11020.48   35578.06  10.82    167.1   4.920   3.802   1749.34   5.47     84.5  -1
  1017.7    924.3    348.1    7.7   6.169  -0.138    11533.20   35574.61  11.03    171.3   4.991   4.061   1461.90   5.08     78.5  -1
  1069.7    975.9    354.9    7.3   5.901  -0.137    12015.63   35570.61  11.26    175.5   5.060   4.328   1230.21   4.58     71.6  -1
  1121.7   1027.5    361.4    6.9   5.651  -0.135    12587.16   35567.31  11.46    179.5   5.128   4.601    912.44   4.01     62.6  -1
  1173.7   1079.1    367.5    6.6   5.418  -0.134    13127.12   35562.91  11.68    183.5   5.194   4.882    640.87   3.31     52.0  -1
  1225.7   1130.8    373.3    6.3   5.201  -0.132    13675.06   35560.58  11.90    187.5   5.258   5.170    331.75   2.30     37.2  -1
  1277.7   1182.5    378.9    6.0   4.997  -0.130    14230.47   35557.28  12.12    191.4   5.321   5.466      0.0    0.0      0.0  -1
  1329.7   1234.2    384.2    5.7   4.807  -0.129    14792.86   35554.03  12.34    195.2   5.382   5.769      0.0    0.0      0.0  -1
  1381.7   1286.0    389.2    5.5   4.628  -0.127    15361.68   35550.88  12.56    199.0   5.442   6.072      0.0    0.0      0.0  -1
  1433.7   1337.7    394.1    5.2   4.461  -0.124    15937.13   35547.75  12.77    202.7   5.500   6.389      0.0    0.0      0.0  -1
  1485.7   1389.5    398.7    5.0   4.304  -0.122    16510.60   35544.69  12.99    206.4   5.557   6.703      0.0    0.0      0.0  -1
  1537.7   1441.3    403.2    4.8   4.156  -0.120    17104.96   35541.63  13.21    210.0   5.613   7.028      0.0    0.0      0.0  -1
  1589.7   1493.2    407.5    4.6   4.016  -0.118    17690.96   35538.64  13.43    213.6   5.668   7.357      0.0    0.0      0.0  -1
  1641.7   1545.0    411.6    4.5   3.885  -0.116    18283.99   35535.75  13.64    217.1   5.722   7.693      0.0    0.0      0.0  -1
  1693.7   1596.9    415.6    4.3   3.761  -0.114    18885.76   35532.88  13.86    220.6   5.774   8.033      0.0    0.0      0.0  -1
  1745.7   1648.7    419.4    4.1   3.644  -0.112    19502.11   35530.03  14.07    224.1   5.826   8.378      0.0    0.0      0.0  -1
  1797.7   1700.6    423.1    4.0   3.533  -0.110    20112.84   35527.28  14.28    227.6   5.877   8.727      0.0    0.0      0.0  -1
  1849.7   1752.5    426.6    3.9   3.428  -0.109    20727.73   35524.67  14.49    231.0   5.926   9.082      0.0    0.0      0.0  -1
  1901.7   1804.3    430.1    3.7   3.328  -0.107    21346.04   35521.78  14.70    234.3   5.975   9.440      0.0    0.0      0.0  -1
  1953.7   1856.2    433.4    3.6   3.234  -0.105    21964.60   35519.08  14.91    237.7   6.023   9.803      0.0    0.0      0.0  -1
  2005.7   1908.1    436.7    3.5   3.144  -0.103    22585.68   35516.48  15.11    241.0   6.070  10.170      0.0    0.0      0.0  -1
  2057.7   1960.0    439.8    3.4   3.058  -0.102    23225.65   35513.84  15.32    244.3   6.117  10.541      0.0    0.0      0.0  -1
  2109.7   2011.9    442.8    3.3   2.977  -0.100    23856.26   35511.31  15.52    247.5   6.163  10.916      0.0    0.0      0.0  -1


AREAS OF EXCESS TEMPERATURE FOR          2000.0000        25.0000

TEMP.(F)       AREA (FT**2)

   1.25        8.656E 05  PARTIAL AREA - CALCULATION VALID TO  T = 2.977
   2.50        5.668E 05  PARTIAL AREA - CALCULATION VALID TO  T = 2.977
   3.75        3.527E 05
   5.00        2.197E 05
   6.25        1.474E 05
   7.50        1.015E 05
   8.75        7.160E 04
  10.00        5.196E 04
  11.25        3.779E 04
  12.50        2.828E 04
  13.75        2.094E 04
  15.00        1.607E 04
  16.25        1.290E 04
  17.50        1.033E 04
  18.75        8.471E 03
  20.00        7.068E 03
  21.25        5.564E 03
  22.50        5.039E 03
  23.75        4.161E 03
  25.00        2.667E 03
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      SITE NO.3 AT GARRISON RESERVOIR: SIZE=4000MW.(LOW LEVEL.

   4000.MEGA WATT          8.-PORT DISCH.          356.13VOL/SEC/JET

 ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

     JET DIAMETER=  8.00FEET                              JET DISCHARGE VELOCITY=  7.08FEET/SEC
     JET DISCHARGE TEMPERATURE= 83.00DEGREE FAHREN        JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
     JET DISCH. ANGLE= 25.00 DEGREES                      JET DISCHARGE DEPTH=100.00FEET
     JET SPACING C-C= 30.00FEET                           WATER BODY DEPTH = 110.0FEET

     X        Y       WIDTH  DILUTION     Q      DELTA-TEMP      S   LOCAL FRD   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

   44.986   20.967   16.008    1.000     712.5  21.7816315   49.612    36.42    25.00    18.485    15.926    11.583
   59.190   28.253   23.027    1.468    1045.8  14.8396263   65.612    18.69    29.46    23.882    19.708    11.867
   72.733   36.736   29.670    1.968    1387.4  11.1857271   81.608    12.29    34.78    27.919    21.838     8.147
   85.398   46.481   35.85C    2.444    1740.7   8.9155016   97.604     9.42    40.38    30.689    22.363     0.0
          TRANSITION POINT TWO
   97.106   57.359   50.756    2.939    2095.0   6.0156965  113.601     3.99    45.22    29.937    15.634     0.0
  107.931   69.134   62.461    3.396    2418.7   5.2055988  129.609     3.30    49.53    32.788     8.846     0.0
  117.883   81.861   73.100    3.831    2728.7   4.6142206  145.605     2.96    53.35    33.916     0.0       0.0
  127.036   94.765   82.94C    4.254    3030.0   4.1554193  161.601     2.77    56.69    33.675     0.0       0.0
          THIS IS FREE SURFACE
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      SITE NO.3 AT GARRISON RESERVOIR: SIZE=4000MW.(AVERAGE LEVEL.

   4000.MEGA WATT          8.-PORT DISCH.          356.13VOL/SEC/JET

 ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

     JET DIAMETER=  8.00FEET                              JET DISCHARGE VELOCITY=  7.08FEET/SEC
     JET DISCHARGE TEMPERATURE= 83.00DEGREE FAHREN        JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
     JET DISCH. ANGLE= 25.00 DEGREES                      JET DISCHARGE DEPTH=100.00FEET
     JET SPACING C-C= 30.00FEET                           WATER BODY DEPTH = 110.0FEET

     X        Y       WIDTH  DILUTION     Q      DELTA-TEMP      S   LOCAL FRD   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

   44.985   20.988   16.036    1.000     712.5  21.7910059   49.613    36.42    25.00    19.485    15.927    11.584
   59.189   28.293   23.327    1.468    1045.8  14.8399172   65.610    18.69    29.46    23.881    19.700    11.867
   72.742   36.745   29.676    1.968    1387.7  11.1838455   81.609    12.28    34.79    27.921    21.839     8.142
   85.419   46.497   35.858    2.445    1741.2   8.9129467   97.606     9.42    40.39    30.692    22.362     0.0
          TRANSITION POINT TWO
   97.111   57.186   50.742    2.940    2093.7   6.0136595  113.603     3.99    45.23    29.945    15.628     0.0
  107.956   69.161   62.486    3.397    2419.4   5.2062055  129.601     3.30    49.53    32.792     8.840     0.0
  117.890   81.888   73.117    3.833    2729.8   4.6123610  145.612     2.96    53.37    33.917     0.0       0.0
  127.036   94.808   82.981    4.256    3031.3   4.1550691  161.610     2.77    56.70    33.670     0.0       0.0
          THIS IS FREE SURFACE
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      SITE NO.3 AT GARRISON RESERVOIR: SIZE=4000MW.(HIGH LEVEL.

   4000.MEGA WATT          8.-PORT DISCH.          356.13VOL/SEC/JET

 ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

     JET DIAMETER=  8.00FEET                              JET DISCHARGE VELOCITY=  7.08FEET/SEC
     JET DISCHARGE TEMPERATURE= 83.00DEGREE FAHREN        JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
     JET DISCH. ANGLE= 25.00 DEGREES                      JET DISCHARGE DEPTH=120.00FEET
     JET SPACING C-C= 30.00FEET                           WATER BODY DEPTH = 130.0FEET

     X        Y       WIDTH  DILUTION     Q      DELTA-TEMP      S   LOCAL FRD   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

   44.986   20.984   16.037    1.000     712.6  21.7900598   49.615    36.42    25.00    18.486    15.927    11.586
   59.185   28.281   23.029    1.468    1045.7  14.8414861   65.606    18.69    29.46    23.880    19.699    11.867
   72.734   36.734   29.670    1.968    1387.4  11.1857216   81.609    12.29    34.78    27.919    21.838     8.147
   85.606   46.484   35.852    2.444    1740.9   8.9147873   97.613     9.42    40.39    30.699    22.362     0.0
          TRANSITION POINT TWO
   97.107   57.361   50.756    2.939    2093.0   6.0158529  113.602     3.99    45.22    29.936    15.635     0.0
  107.928   69.132   62.455    3.396    2418.6   5.2059708  129.607     3.30    49.52    32.787     8.873     0.0
  117.846   81.844   73.399    3.831    2728.7   4.6143017  145.611     2.96    53.35    33.916     0.0       0.0
  127.036   94.767   82.933    4.256    3029.8   4.1557045  161.600     2.77    56.68    33.676     0.0       0.0
  139.447  108.328   92.197    4.670    3324.2   3.7853708  177.605     2.67    59.56    31.637     0.0       0.0
          THIS IS FREE SURFACE
   PLANT SITE NO.4 AT GARRISON RESERVOIR NEAR NEW TOWN: SIZE=2000MW.:LOW LEVEL

 2000.MEGA WATT        4.-PORT DISCH.        356.13VOL/SEC/JET

ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

   JET DIAMETER=  7.00FEET                          JET DISCHARGE VELOCITY=  9.25FEET/SEC
   JET DISCHARGE TEMPERATURE= 85.0DEGREE FAHREN     JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
   JET DISCH. ANGLE= 15.00 DEGREES                  JET DISCHARGE DEPTH= 60.00FEET
   JET SPACING C-C= 40.00FEET                       WATER BODY DEPTH =  70.0FEET

   X        Y      WIDTH  DILUTION     Q     DELTA-TEMP      S   LOCAL FRD   ANGLE    3D.WIDTH  5D.WIDTH  10D.WIDTH
                                                                                       16.172    13.935    10.135
  41.928   11.235   14.003   1.000    712.4  21.7861187   43.407   71.02     15.00    21.150    17.452    10.532
  55.353   15.137   20.378   1.466   1045.5  14.8732738   57.402   34.19     17.53    25.120    19.690     7.539
  68.588   19.719   26.634   1.934   1377.7  11.2648695   71.407   20.63     20.86    28.174    20.647     0.0
  81.479   25.131   32.697   2.409   1716.0   9.0442142   85.402   14.30     24.81    30.303    20.219     0.0
  93.996   31.471   38.508   2.890   2060.2   7.5331688   99.405   10.93     29.16    31.527    18.126     0.0
 105.900   38.763   44.001   3.386   2412.0   6.4364425  113.407    9.00     33.69    31.899    13.943     0.0
 117.225   46.971   49.171   3.893   2773.0   5.5967751  127.402    7.85     38.18
        TRANSITION POINT TWO
 127.932   55.982   64.619   4.395   3130.4   4.0221958  141.405    3.64     41.92    24.740     0.0       0.0
        THIS IS FREE SURFACE
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   PLANT SITE NO.4 AT GARRISON RESERVOIR NEAR NEW TOWN:SIZE=2000MW.:AVERAGE LEVEL

 2000.MEGA WATT        4.-PORT DISCH.        356.13VOL/SEC/JET

ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

   JET DIAMETER=  7.00FEET                          JET DISCHARGE VELOCITY=  9.25FEET/SEC
   JET DISCHARGE TEMPERATURE= 85.0DEGREE FAHREN     JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
   JET DISCH. ANGLE= 15.00 DEGREES                  JET DISCHARGE DEPTH= 68.00FEET
   JET SPACING C-C= 40.00FEET                       WATER BODY DEPTH =  78.0FEET

   X        Y      WIDTH  DILUTION     Q     DELTA-TEMP      S   LOCAL FRD   ANGLE    3D.WIDTH  5D.WIDTH  10D.WIDTH
                                                                                       16.173    13.935    10.135
  41.929   11.235   14.034   1.000    712.5  21.7633462   43.409   71.02     15.00    21.151    17.453    10.531
  55.359   15.138   20.381   1.469   1043.6  14.8712730   57.407   34.18     17.53    25.128    19.689     7.546
  68.571   19.717   26.631   1.936   1377.5  11.2666388   71.405   20.64     20.86    28.170    20.647     0.0
  81.463   25.129   32.689   2.409   1719.5   9.0467790   85.403   14.31     24.80    30.299    20.222     0.0
  93.926   31.496   38.487   2.891   2059.2   7.5365295   99.401   10.94     29.15    31.526    18.136     0.0
 105.865   38.742   43.993   3.385   2410.8   6.4375143  113.408    9.00     33.60    31.890    13.949     0.0
 117.186   46.941   49.151   3.891   2771.5   5.5996656  127.406    7.85     38.16
        TRANSITION POINT TWO
 127.884   55.961   64.561   4.393   3128.6   4.0244331  141.404    3.64     41.90    24.743     0.0       0.0
 137.998   65.992   74.814   4.867   3466.7   3.6319628  155.402    3.18     45.38    25.133     0.0       0.0
        THIS IS FREE SURFACE
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   PLANT SITE NO.4 AT GARRISON RESERVOIR NEAR NEW TOWN:SIZE=2000MW.:HIGH LEVEL

 2000.MEGA WATT        4.-PORT DISCH.        356.13VOL/SEC/JET

ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

   JET DIAMETER=  7.00FEET                          JET DISCHARGE VELOCITY=  9.25FEET/SEC
   JET DISCHARGE TEMPERATURE= 85.0DEGREE FAHREN     JET DISCHARGE DENSITY= 0.9961564GRAM PER ML
   JET DISCH. ANGLE= 15.00 DEGREES                  JET DISCHARGE DEPTH= 80.00FEET
   JET SPACING C-C= 40.00FEET                       WATER BODY DEPTH =  90.0FEET

   X        Y      WIDTH  DILUTION     Q     DELTA-TEMP      S   LOCAL FRD   ANGLE    3D.WIDTH  5D.WIDTH  10D.WIDTH
                                                                                       16.174    13.935    10.136
  41.931   11.235   14.009   1.000    712.5  21.7823029   43.410   71.01     15.00    21.152    17.494    10.531
  55.363   15.138   20.393   1.465   1043.7  14.8701286   57.409   34.18     17.53    25.129    19.690     7.542
  68.577   19.719   26.634   1.934   1377.6  11.2696488   71.402   20.63     20.86    28.173    20.647     0.0
  81.480   25.136   32.696   2.409   1715.9   9.0446272   85.405   14.30     24.81    30.302    20.220     0.0
  93.956   31.474   38.499   2.892   2060.0   7.5339289   99.407   10.93     29.16    31.526    18.129     0.0
 105.845   38.765   43.995   3.386   2411.6   6.4353552  113.409    9.00     33.69    31.849    13.953     0.0
 117.216   46.970   49.163   3.892   2772.4   5.5978966  127.402    7.85     38.17
        TRANSITION POINT TWO
 127.922   55.979   64.596   4.394   3129.7   4.0229940  141.404    3.64     41.92    24.741     0.0       0.0
 138.063   65.862   74.854   4.869   3448.0   3.6105485  155.406    3.18     45.39    23.118     0.0       0.0
 147.984   75.878   84.376   5.327   3794.1   3.3185492  169.404    2.91     48.59    18.953     0.0       0.0
        THIS IS FREE SURFACE
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      PLANT SITE NO.5 AT FORT PECK RESERVOIR: CAPACITY=1000MW.(LOW LEVEL)

   1000.MEGA WATT          2.-PORT DISCH.         356.13VOL/SEC/JET

 ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

      JET DIAMETER=  7.00FEET                              JET DISCHARGE VELOCITY=  9.25FEET/SEC
      JET DISCHARGE TEMPERATURE= 83.00DEGREE FAHREN        JET DISCHARGE DENSITY= 0.9961356GRAM PER ML
      JET DISCH. ANGLE= 10.00 DEGREES                      JET DISCHARGE DEPTH= 50.00FEET
      JET SPACING C-C= 50.00FEET                           WATER BODY DEPTH =  60.0FEET

      X         Y      WIDTH  DILUTION      Q     DELTA-TEMP      S   LOCAL FRO   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

    42.769    7.534   14.004    1.000    712.6  21.7835081   43.400    71.02    10.00    16.175    13.939    10.135
    56.467   13.267   20.414    1.468   1045.1  14.8755426   57.400    33.68    12.60    21.187    17.486    10.952
    70.021   13.708   26.721    1.932   1376.2  11.2774025   71.400    20.21    16.05    25.274    19.767     7.600
    83.314   15.045   32.855    2.406   1712.5   9.0038057   85.400    13.87    20.20    28.131    20.785     0.0
    96.760   21.391   38.742    2.883   2055.6   7.5576167   99.407    10.59    25.86    30.567    20.626     0.0
   108.665   29.775   44.313    3.371   2401.1   6.4635572  113.403     8.57    29.75    31.866    18.617     0.0
   120.500   37.248   49.951    3.872   2757.6   5.6278791  127.400     7.63    34.65    32.231    13.976     0.0
   131.663   45.662   54.626    4.387   3126.4   4.9671621  141.405     6.76    38.34    31.700     0.0       0.0
          THIS IS FREE SURFACE
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      PLANT SITE NO.5 AT FORT PECK RESERVOIR: SIZE=1000MW.(AVERAGE LEVEL)

   1000.MEGA WATT          2.-PORT DISCH.         356.13VOL/SEC/JET

 ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

      JET DIAMETER=  7.00FEET                              JET DISCHARGE VELOCITY=  9.25FEET/SEC
      JET DISCHARGE TEMPERATURE= 83.00DEGREE FAHREN        JET DISCHARGE DENSITY= 0.9961356GRAM PER ML
      JET DISCH. ANGLE= 10.00 DEGREES                      JET DISCHARGE DEPTH=120.00FEET
      JET SPACING C-C= 50.00FEET                           WATER BODY DEPTH = 130.0FEET

      X         Y      WIDTH  DILUTION      Q     DELTA-TEMP      S   LOCAL FRO   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

    42.761    7.540   14.010    1.001    712.7  21.7746124   43.421    70.96    10.00    16.178    13.939    10.137
    56.479   13.261   20.418    1.465   1043.9  14.8724489   57.417    33.88    12.60    21.191    17.486    10.952
    70.051   13.716   26.733    1.933   1376.8  11.2723456   71.420    20.22    16.06    25.228    19.770     7.589
    83.363   14.096   32.466    2.405   1712.8   9.0608865   85.407    13.86    20.21    28.361    20.785     0.0
    96.279   21.612   38.755    2.886   2056.2   7.5550537   99.415    10.49    24.87    30.550    20.626     0.0
   108.702   29.926   44.376    3.372   2401.8   6.4610605  113.402     8.57    29.76    31.866    18.611     0.0
   120.967   37.298   49.993    3.873   2758.6   5.6299508  127.410     7.63    34.66    32.230    13.959     0.0
   131.726   45.719   54.662    4.389   3125.9   4.9669000  141.417     6.79    39.36    31.696     0.0       0.0
   142.185   54.995   59.026    4.921   3504.7   4.4282389  155.404     6.36    43.71    30.709     0.0       0.0
          TRANSITION POINT TWO
   151.965   65.016   71.308    5.470   3896.1   3.2316581  169.412     3.56    47.90    13.757     0.0       0.0
   161.190   75.535   80.474    6.008   4279.8   2.9619927  183.420     3.03    50.56     0.0       0.0       0.0
   169.767   86.616   89.037    6.532   4652.3   2.7361867  197.407     2.85    53.17     0.0       0.0       0.0
   177.890   94.015   98.276    7.346   5016.9   2.5587167  211.415     2.73    55.87     0.0       0.0       0.0
   185.662  109.764  106.950    7.556   5380.6   2.3601631  225.402     2.65    58.11     0.0       0.0       0.0
   192.666  121.796  114.158    8.099   5760.0   2.1935666  239.410     2.63    60.11     0.0       0.0       0.0
          THIS IS FREE SURFACE
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      PLANT SITE NO.5 AT FORT PECK RESERVOIR: SIZE=1000MW.(HIGH LEVEL)

   1000.MEGA WATT          2.-PORT DISCH.         356.13VOL/SEC/JET

 ROW BUOYANT JETS IN AN ARBITRARILY DENSITY STRATIFIED STAGNANT ENVIRONMENT

      JET DIAMETER=  7.00FEET                              JET DISCHARGE VELOCITY=  9.25FEET/SEC
      JET DISCHARGE TEMPERATURE= 83.00DEGREE FAHREN        JET DISCHARGE DENSITY= 0.9961356GRAM PER ML
      JET DISCH. ANGLE= 10.00 DEGREES                      JET DISCHARGE DEPTH=140.00FEET
      JET SPACING C-C= 50.00FEET                           WATER BODY DEPTH = 190.0FEET

      X         Y      WIDTH  DILUTION      Q     DELTA-TEMP      S   LOCAL FRO   ANGLE    30.WIDTH  50.WIDTH  100.WIDTH

    42.766    7.560   14.011    1.001    712.8  21.7726894   43.423    70.95    10.00    16.179    13.939    10.137
    56.490   13.266   20.426    1.465   1043.8  14.8886902   57.423    33.85    12.60    21.198    17.486    10.951
    70.057   13.716   26.733    1.933   1376.8  11.2723438   71.421    20.22    16.36    25.228    19.770     7.588
    83.352   14.357   32.468    2.405   1713.3   9.0597109   85.420    13.86    20.22    28.363    20.785     0.0
    96.277   23.612   38.796    2.884   2054.1   7.5552790   99.418    10.49    24.87    30.550    20.626     0.0
   108.709   29.829   44.326    3.172   2402.0   6.4612150  113.417     8.57    29.77    31.866    18.610     0.0
   120.966   37.290   49.952    3.873   2758.6   5.6762169  127.415     7.63    34.66    32.230    13.962     0.0
   131.713   45.711   54.638    4.388   3125.4   4.9056067  141.414     6.75    39.35    31.697     0.0       0.0
   142.181   54.992   59.017    4.920   3504.5   4.4289078  155.412     6.36    43.71    30.710     0.0       0.0
          TRANSITION POINT TWO
   151.956   65.036   71.296    5.469   3895.6   3.2321033  169.410     3.34    47.90    13.762     0.0       0.0
   161.122   75.576   80.854    6.008   4279.0   2.9624904  183.409     3.04    50.98     0.0       0.0       0.0
   169.717   86.603   89.401    6.531   4652.0   2.7065739  197.407     2.85    53.36     0.0       0.0       0.0
   177.816   98.311   98.261    7.046   5018.3   2.5090208  211.406     2.73    55.87     0.0       0.0       0.0
   185.652  109.766  106.391    7.556   5380.3   2.3401861  225.406     2.65    58.11     0.0       0.0       0.0
   192.615  121.799  114.146    8.058   5759.6   2.1937056  239.402     2.60    60.11     0.0       0.0       0.0
   199.699  136.032  121.771    8.560   6097.2   2.0690461  253.401     2.57    61.91     0.0       0.0       0.0
          THIS IS FREE SURFACE
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APPENDIX VI

Final Draft Report

to

The Environmental Protection Agency

Contract No. 68 01 2659

RECONNAISSANCE EFFORT TO QUANTIFY DISTRIBUTION OF TRACE ELEMENTS IN SOIL, SEDIMENT, AND SURFACE WATER OF THE MISSOURI RIVER BASIN, WESTERN SOUTH DAKOTA

(NGPRP NO. 7)

Mr. Robert Stack
Geologist
South Dakota Geological
Survey
Vermillion, South Dakota

JUNE, 1975

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SUMMARY AND CONCLUSIONS

The study area is located in northwestern South Dakota. Sampling sites and streams are displayed in Figure 1 with locations of the sample sites in the Sample Index.

The following is a summary of the study and our conclusions:

1. With the exception of Spearfish Creek, the streams are highly saline.
2. Whitewood Creek has been contaminated by mine tailings with high arsenic levels shown in both the water from the stream and cottonwood leaves from trees adjacent to the stream.
3. A majority of the rock and soil samples are highly seleniferous as well as containing above normal amounts of arsenic.
4. There is a correlation between rock type and dominant cation in the surface waters.
5. Trace element composition is the rocks and soils varied widely and with the exception of selenium.
6. Soils of the area are immature and show a close relationship with the parent material.

RECOMMENDATIONS

1. Studies by Keith, et al. (1974) have shown selenium to be a potential pollutant from any coal fired power plants in the area. In view of this and the high selenium background of the area any addition of selenium should be scrutinized closely. It is strongly recommended further studies be made of selenium content of the waters (both ground and surface waters) of the area.
2. Because of the abnormally dry conditions during the stream sampling for this study, it is recommended the streams be re-sampled at several time intervals under normal precipitation conditions.
3. Further sampling is needed to delineate any trends and to establish a reliable baseline for future monitoring.
4. It is recommended future studies concentrate on the Pierre, Fox Hills, Hell Creek, and Ludlow Formations.

INTRODUCTION

The study area is located in northwestern South Dakota with sampling localities in Harding, Butte, Lawrence, Perkins, Ziebach, and Haakon Counties (Figure 1). The area encompassed is approximately 14,000 square miles.

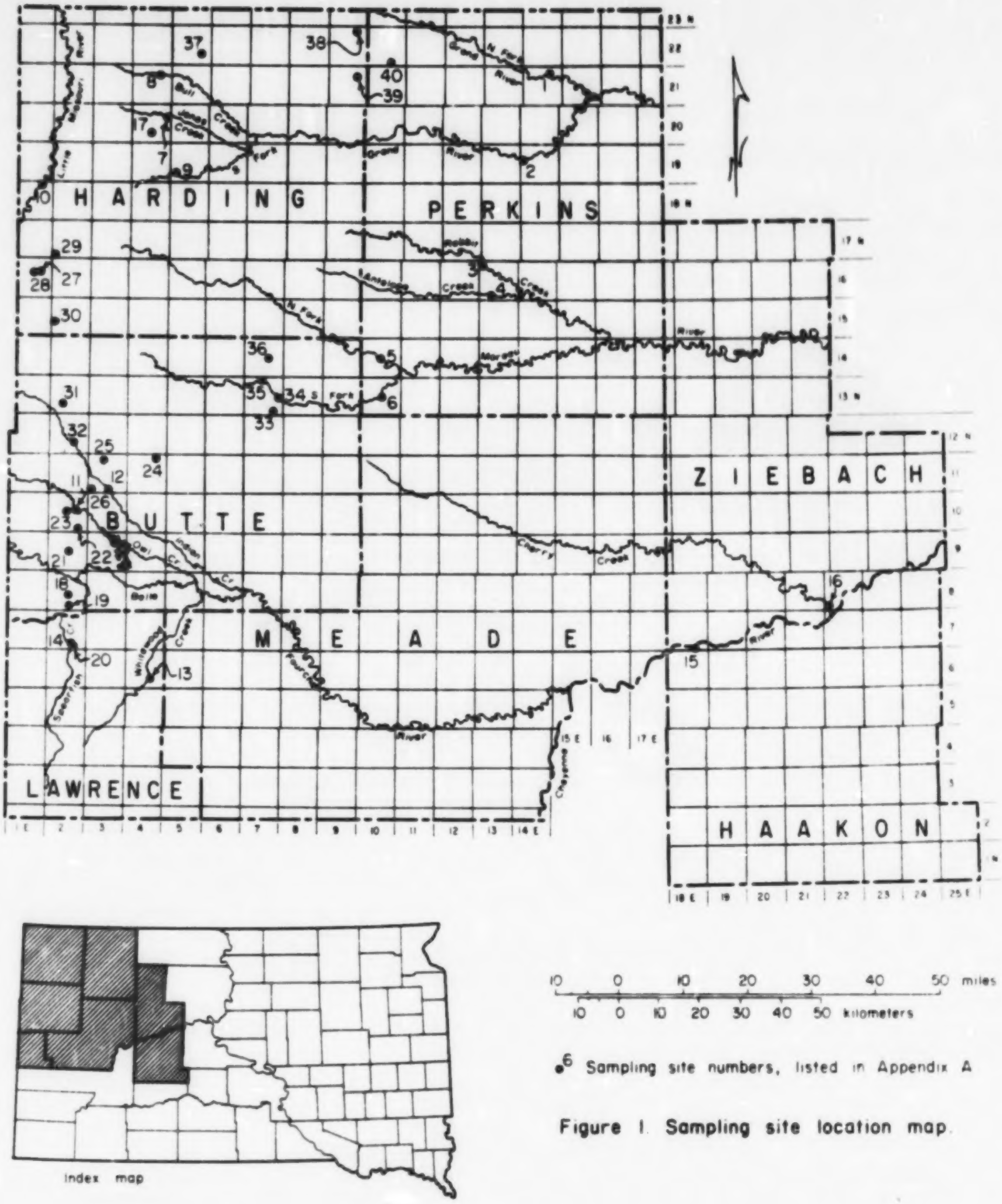

HARDING
PERKINS
ZIEBACH
BUTTE
MEADE
LAWRENCE
HAAKON
Little Missouri River
Bull Creek
Jones Creek
S Fork
Grand River
N Fork Grand River
Rabbit Creek
Antelope Creek
N Fork
Moreau River
S Fork
Cherry Creek
Indian Cr
Owl Cr
Belle Fourche River
Whitewood Creek
Spearfish Cr
Cheyenne River
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
23 N
22
21
20
19
18 N
17 N
16
15
14
13 N
12 N
11
10
9
8
7
6
5
4
3
2
1 N
1 E
2
3
4
5
6
7
8
9
10
11
12
13
14 E
15 E
16
17 E
18 E
19
20
21
22
23
24
25 E
10 0 10 20 30 40 50 miles
10 0 10 20 30 40 50 kilometers
6 Sampling site numbers, listed in Appendix A
Index map

Figure 1. Sampling site location map.

With the exception of Lawrence County, which contains part of the Black Hills, the area is a rolling prairie with local badlands and isolated buttes. Vegetation is predominately prairie grasses with conifers in the Black Hills and on isolated buttes; the drainages on the prairie contain isolated stands of deciduous trees.

Population density is low (approximately 3.6 persons/square mile, 1970 census) with the economic base of the area centered on livestock and limited crop production. Current mining and industrial activity is centered at the Homestake Gold Mine, Lawrence County, and mining and milling of bentonite in the vicinity of Belle Fourche, Butte County. In addition to present mining there are numerous small defunct uranium mines with attendant spoil piles in Harding County.

CLIMATE

Climate of the area is classified as semi-arid continental with mean annual precipitation ranging from less than 14 inches at Camp Crook to more than 24 inches near Deadwood (Figure 2). Average annual lake evaporation is shown in Figure 3. The bulk of the precipitation is received from April to September. During this study the area had received less than normal precipitation and was experiencing a dry condition (Figure 4). Temperatures range from -20^{o}F or lower during the winter to 100^{o}F or more in the summer with a mean annual temperature of approximately 44^{o}F (Figure 5).

SAMPLING

Sampling for the project was performed during two one-week periods. Water, vegetation, and some rock and soil samples were collected during the week of June 24, 1974, with the final rock and soil samples collected during the week of September 30, 1974. Samples were taken from the major geologic units in the area and the soils developed thereon. Figure 1 is a map of the area with the sampling sites plotted. The Sample Index gives the locations and descriptions of the sampling sites. The sampling procedure was carried out in as systematic a manner as outcrops would permit, and the geologic section was sampled from the Triassic through the Miocene. It is this portion of the geologic section over which all or a part of the drainages flow. The upper Cretaceous (Pierre, Fox Hills, and Hell Creek Formations) and the Paleocene (Ludlow, Cannonball, and Tongue River Formations) have the greatest surface area exposed; consequently, a majority of the samples were collected from these units.

A total of 85 rock and soil samples, 16 surface water samples, and 12 vegetation samples were collected. The water samples were analyzed for conductivity, total dissolved solids, total alkalinity, pheno alkalinity, pH, Na, K, Ca, Mg, Cl, SO_4, F, Zn, Fe, Mn, As, Mo, Al, V, Hg, and Cu.

The vegetation samples were cottonwood leaves which were analyzed for: Cd, Cr, Sr, Cu, Pb, Ni, As, Se, and Hg. The rock and soil samples

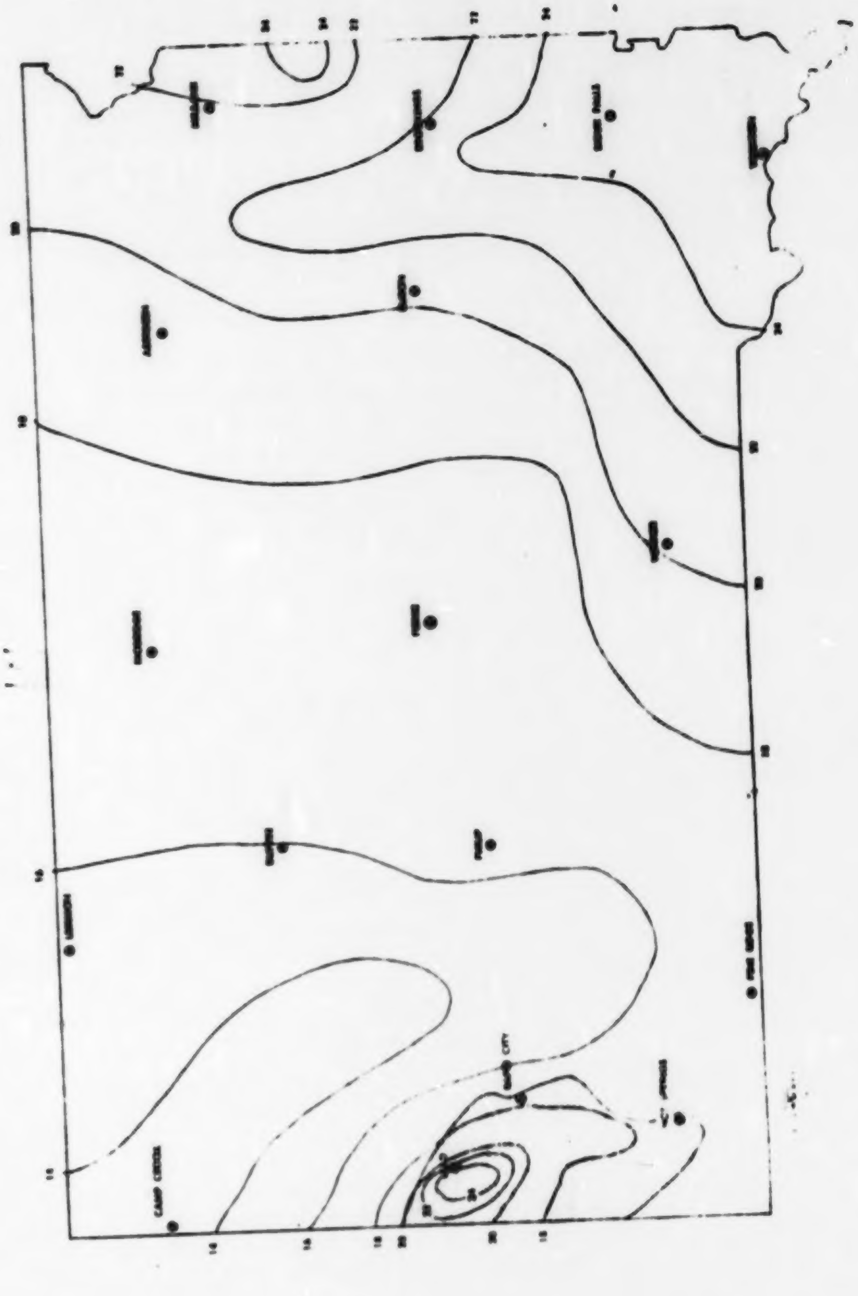
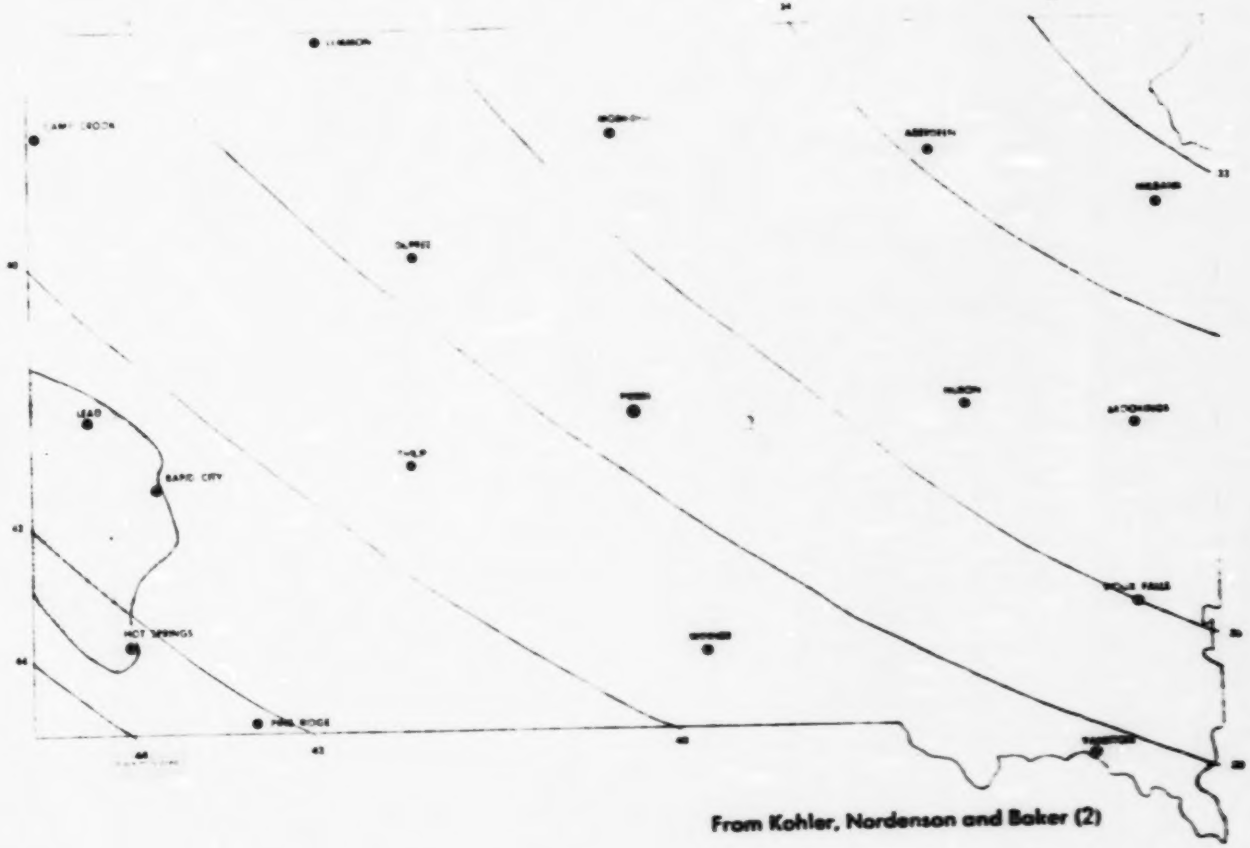

CAMP CROOK
LEMMON
RAPID CITY
HOT SPRINGS
PINE RIDGE

Figure 2. Annual Average Precipitation (Inches)


CAMP CROOK
LEAD
RAPID CITY
HOT SPRINGS
PINE RIDGE
SIOUX FALLS
40
42
44

From Kohler, Nordenson and Baker (2)

Figure 3. Average Annual Lake Evaporation in Inches

(Period 1946-1955)

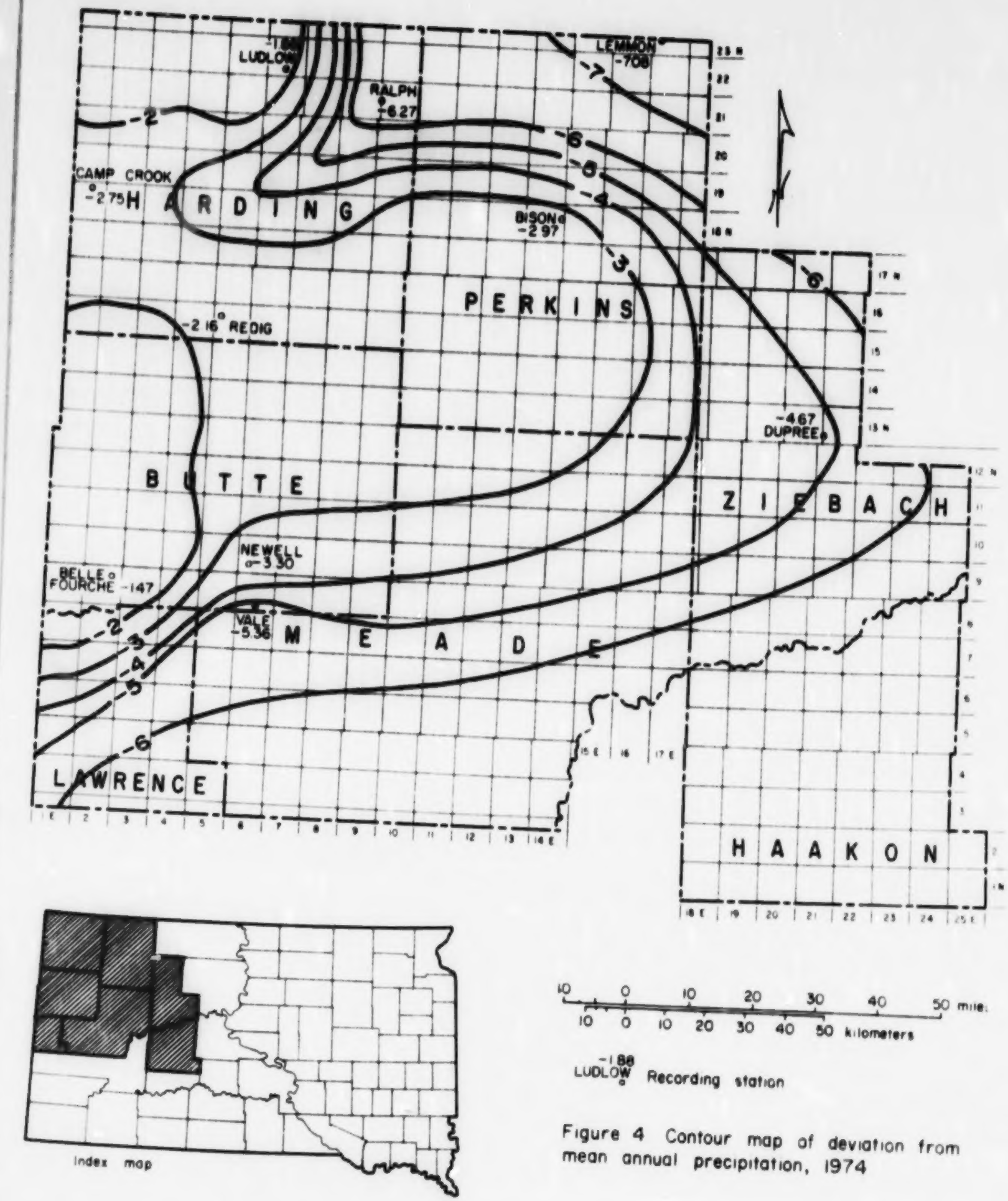

LUDLOW -1.88
LEMMON -7.08
RALPH -6.27
CAMP CROOK -2.75
HARDING
BISON -2.97
PERKINS
-2.16 REDIG
BUTTE
-4.67 DUPREE
ZIEBACH
NEWELL -3.30
BELLE FOURCHE -1.47
VALE -5.36
MEADE
LAWRENCE
HAAKON
-2
-3
-4
-5
-6
-7
Index map
10 0 10 20 30 40 50 miles
10 0 10 20 30 40 50 kilometers
-1.88 LUDLOW Recording station

Figure 4 Contour map of deviation from mean annual precipitation, 1974

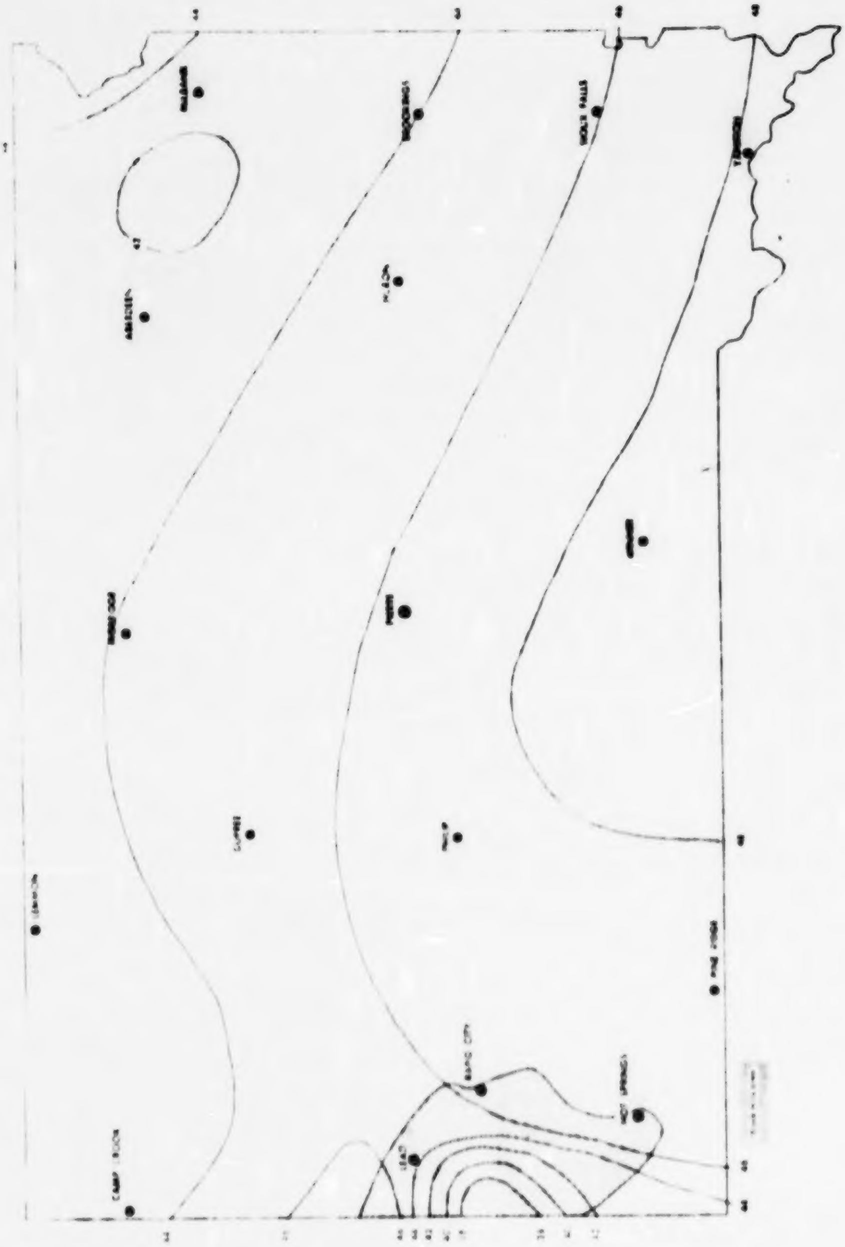

CAMP CROOK
LEAD
RAPID CITY
HOT SPRINGS
ABERDEEN
HURON
BROOKINGS
SIOUX FALLS

Figure 5. Annual Average Mean Temperature (°F)

were analyzed for Hg, As, and Se with Cu, Zn, V, S, P, Mn, Sr, As, and Se being determined semi-quantitatively by x-ray fluorescence. The lignite and carbonaceous shale samples were analyzed for: percent ash, Cu, Se, As, V, Pb, Cd, Cr, Co, Sr, Ni, Zn, and Hg.

REGIONAL GEOLOGY

The study area is predominately upper Cretaceous and Tertiary rocks; however, rocks as old as Triassic were sampled (Figure 6). Approximately 90 percent of the rocks at the surface are Late Cretaceous or younger (Plate 1). The area encompasses portions of two major geologic structures, the Williston Basin and the Black Hills (Figure 7). The Williston Basin includes a large portion of western North and South Dakota and eastern Montana. The rocks in the Basin show little evidence of structural activity and only undulatory, poorly defined folds and small scale faults have been found. In contrast, the southwestern part of the study area is located on the northern flank of the Black Hills. This area was tectonically active during the Late Cretaceous and early Tertiary. This tectonic activity produced a domal structure which has been eroded exposing the older rocks in the center of the dome.

STRATIGRAPHY

The oldest geologic unit sampled was the Triassic Spearfish-Gypsum Springs unit which reaches a maximum thickness of 500 feet. This unit consists of distinctive red-brown sandy-silty shales with abundant gypsum beds up to 30 feet thick. Mineralogically the Spearfish has approximately equal amounts of quartz and clay with anomalously high feldspar contents and a clay fraction dominated by illite (Plate 2).

Included in the Early Cretaceous Inyan Kara Group are the Lakota and the Fall River Formations which attain a combined thickness of up to 350 feet. These units are extremely variable in lithology. They range from fine-grained sandstones and shales to siltstones, limestones, and some lignite beds. The Inyan Kara group is quartzose, as would be expected, with a clay fraction dominated by kaolinite (Plate 2).

The Mowry Shale Member (of the Graneros Shale) is 200-250 feet thick and is composed of light-gray shale which is commonly silicified. The shale is frequently interbedded with thin fine-grained sands. Bentonite beds up to 3 to 4 feet thick are common in this unit. The one sample of the Mowry Shale contains mostly clay minerals with the clay fraction dominated by smectite (Plate 2).

The Greenhorn Limestone varies in thickness from 35 to 65 feet of thin limestones interbedded with a calcareous shale. The Greenhorn contains abundant calcite with subordinate quartz. The clay fraction is primarily illite (Plate 2).

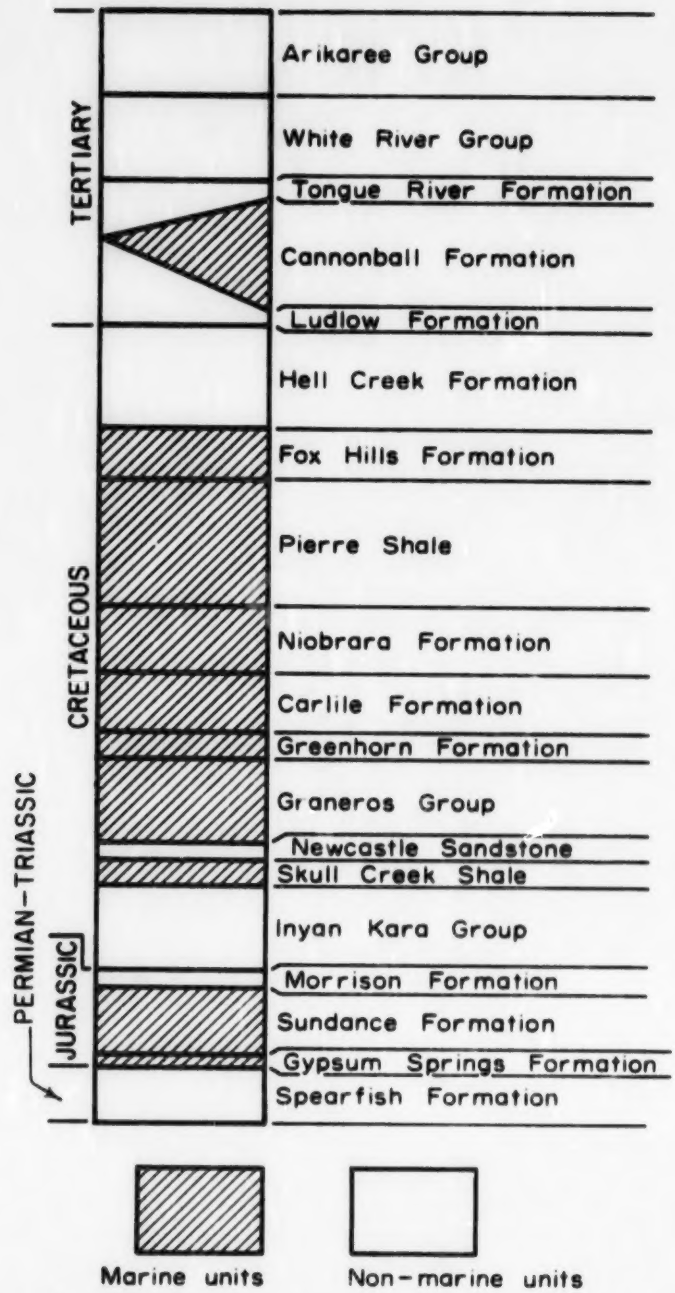
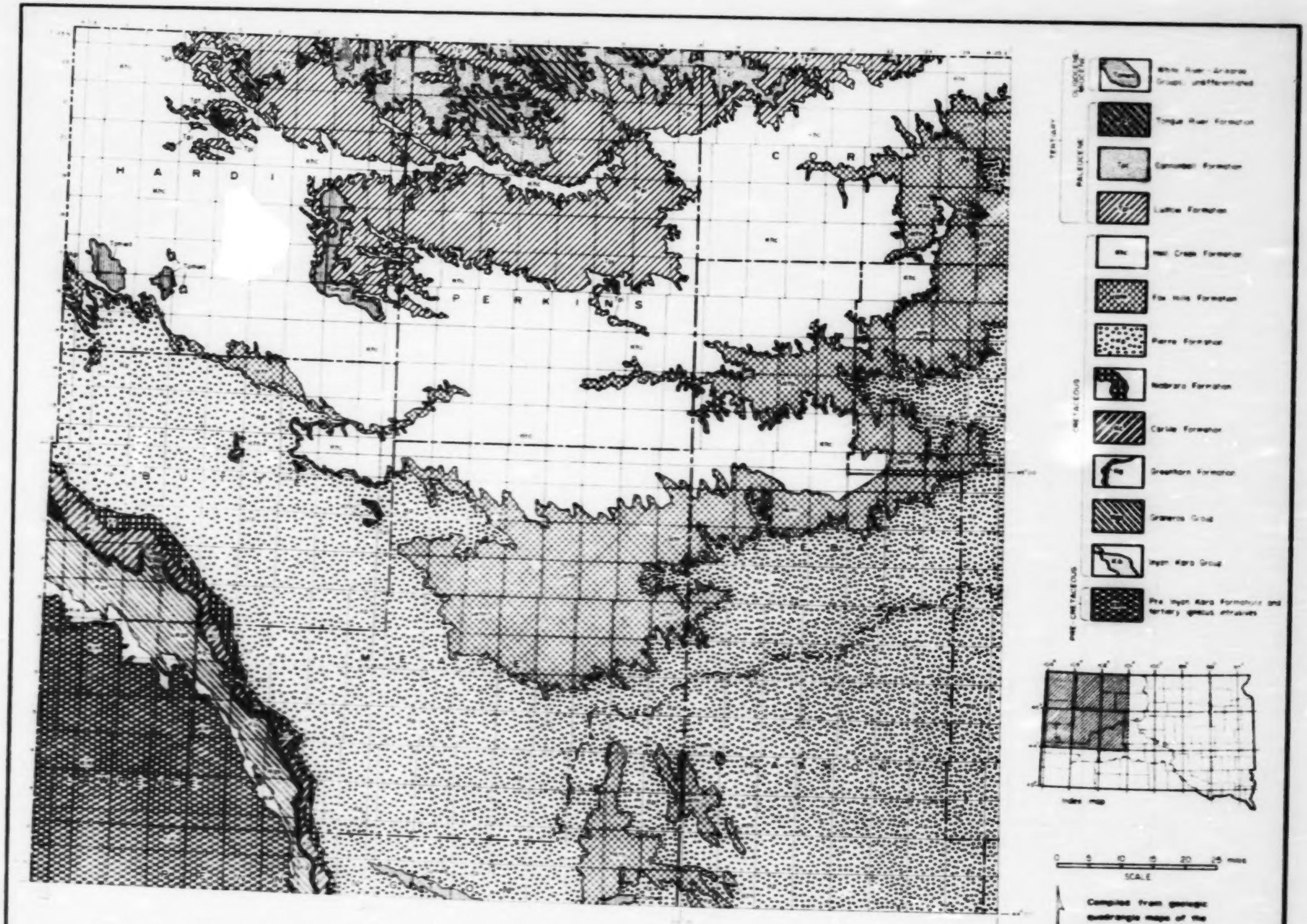

TERTIARY
CRETACEOUS
JURASSIC
PERMIAN-TRIASSIC
Arikaree Group
White River Group
Tongue River Formation
Cannonball Formation
Ludlow Formation
Hell Creek Formation
Fox Hills Formation
Pierre Shale
Niobrara Formation
Carlile Formation
Greenhorn Formation
Graneros Group
Newcastle Sandstone
Skull Creek Shale
Inyan Kara Group
Morrison Formation
Sundance Formation
Gypsum Springs Formation
Spearfish Formation
Marine units
Non-marine units

Figure 6. Geologic column of units exposed in study area. (not to scale)


H A R D I
P E R K I N S
C O R
B U T T E
M E A D E
Khc
Tsl
Tcm
TERTIARY
OLIGOCENE-MIOCENE
PALEOCENE
CRETACEOUS
PRE-CRETACEOUS
White River-Arikaree Groups, undifferentiated
Tongue River Formation
Cannonball Formation
Ludlow Formation
Hell Creek Formation
Fox Hills Formation
Pierre Formation
Niobrara Formation
Carlile Formation
Greenhorn Formation
Graneros Group
Inyan Kara Group
Pre-Inyan Kara Formations and tertiary igneous intrusives
Index map
0 5 10 15 20 25 miles
SCALE

Compiled from geologic quadrangle maps of the South Dakota Geological Survey

Plate I. Geologic map of northwesten South Dakota.

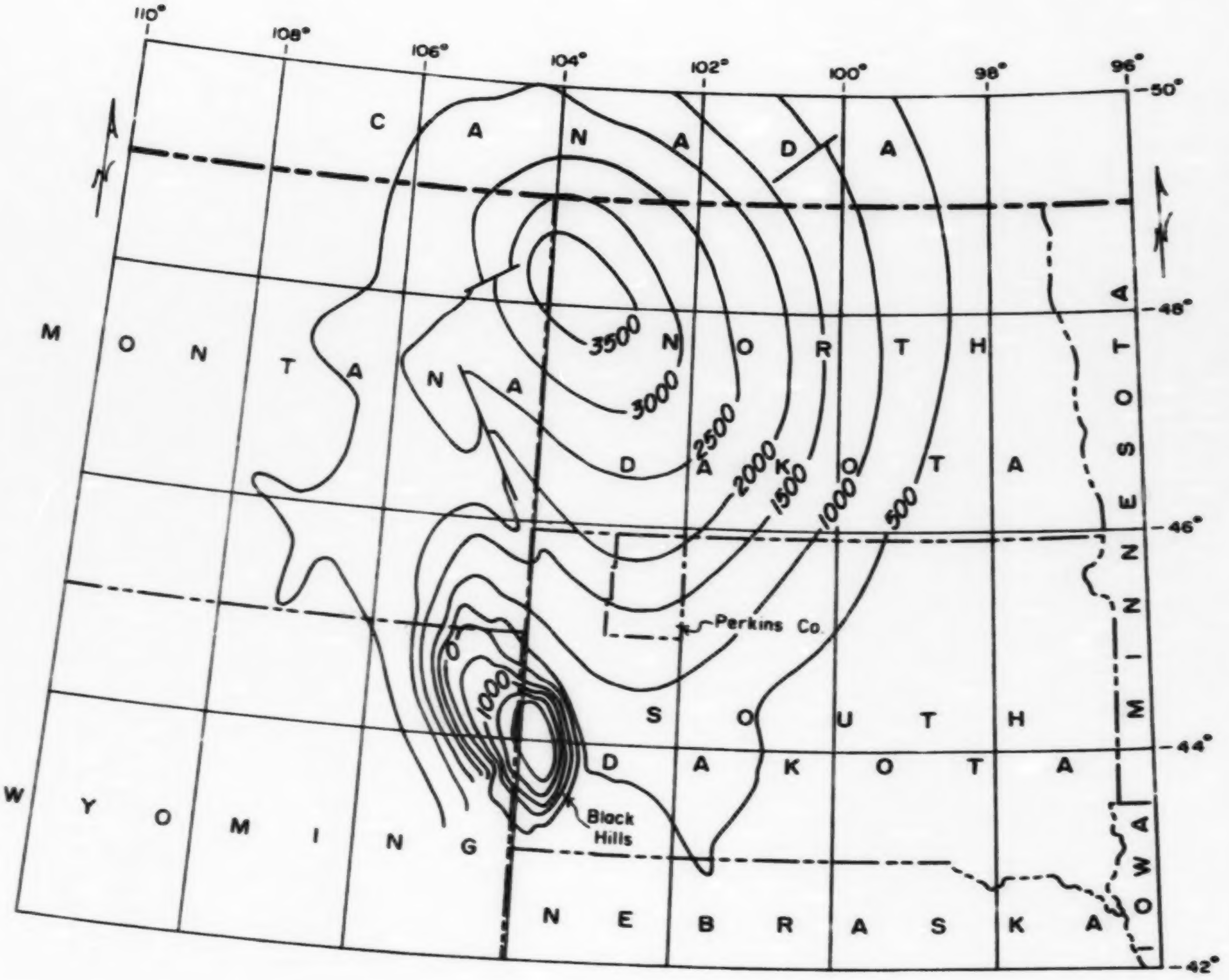

110°
108°
106°
104°
102°
100°
98°
96°
50°
48°
46°
44°
42°
CANADA
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
NEBRASKA
MINNESOTA
IOWA
3500
3000
2500
2000
1500
1000
500
0
1000
Perkins Co.
Black Hills
N
N
0
50
100
200
300 miles

Figure 7. Basement contour map of Williston Basin area (after King, 1969)

Datum = sea level   Contour interval = 500 meters

Sample number (lithology) and geologic unit	Quartz	Cristobalite	Plagioclase	K-feldspar	Calcite	Mixed calcite	Dolomite	Siderite	Gypsum	Jarosite	Alunite	Zeolite	Pyrite	Clay minerals	Total percentage	Kaolinite	Chlorite	Illite	Smectite	Mix layered	comments
Spearfish-Gypsum Springs																					
20 98-C (gypsum)									100						100						
20 98-B (soil)	30	—	15	17	3	—	35	—	—	—	—	—	4(?)	36	140	9	5	83	—	3	
20 98-A (shale)	36	—	10	2	5	—	15	—	—	—	—	—	2(?)	34	104	7	29	50	10	4	
Inyan Kara Grp																					
19 97-C (shale)	49	—	—	2	—	—	—	—	—	—	—	—	Tr ?	23	74	100	—	—	—	—	high organic content
19 97-B (shale)	32	—	1	1	—	—	—	—	—	—	—	—	—	54	88	42	—	30	—	28	
19 97-D (sandstone)	90	—	—	—	—	—	—	—	—	—	—	—	—	10	100	100					
Graneros Grp																					
18 97-A (shale)	34	—	3	Tr						14				45	102	—	Tr	5	78	17	
Greenhorn Fm																					
21 99-A (chalk)	19	—	—	—	75	—	—	—	—	—	—	—	Tr	28	122	10	0	69	0	21	
Carlile Fm																					
23 100-A (shale)	24	—	2	3	—	2	2	—	3	—	—	—	—	51	87	28	—	39	—	33	
22 99-B (shale)	29	—	3	2	—	4	7	3	5	—	1	—	—	65	119						no clay peaks
23 100-B (bentonite)														98	98	100					
Niobrara Fm																					
23 100-C (chalk)	57	—	—	—	32	—	38	—	—	—	—	—	—	23	100	—	—	—	—	—	Dolomite is iron rich
Pierre Shale Fm																					
24 100-D (shale)	21	—	5	1	—	3	1	3	2	—	—	—	4	64	102	—	—	56	44	—	
28 102-D (bentonite)	26	—	4	—	8	—	—	—	—	—	—	—	—	51	89	—	Tr	13	87	—	
28 102-E (shale)	24	—	3	3	Tr	2	—	—	—	—	—	—	—	68	100						
30 103-E (soil)	19	5	3	2	—	2	Tr	—	—	—	—	Tr?	—	77	108	—	—	28	72	—	
30 103-D (shale)	20	Tr	1	2	—	4	Tr	—	—	1	2	—	—	74	104						no clay peaks
31 104-A (shale)	19	—	3	2	—	—	—	—	Tr	Tr?	1	—	6	64	95	Tr	—	14	20	66	
31 104-B (weathered shale)	20	—	4	3	—	4			3	—	1	—	Tr?	60	95	—	—	—	100	—	
32 104-C (shale)	21	Tr?	3	3	1	3	5	—	3	—	1	—	—	66	106	—	Tr	25	25	50	
34 105-E (concretion)	5	—	—	—	55	—	—	3	—	—	—	—	—	17	80			25	75		
25 101-B (concretion)	9	—	—	—	41	—	2	1	7	—	—	—	2	20	82						no clay peaks
26 101-C ("soils")	27	—	3	1	—	—	6	10	2	—	—	—	—	54	103	15	Tr	85	Tr	—	"alkali" spot on Mud Butte
25 101-A (shale)	30	—	2	2	—	—	—	—	5	—	2	—	—	70	111	—	—	83	—	17	
Fox Hills Fm																					
27 102-C (soil)	40	—	8	5	2	—	—	—	—	—	Tr?	—	—	28	82	—	3	18	79	—	
33 105-A (sandstone)	38	—	11	3	—	3	5	—	—	4	—	—	—	29	91	15	13	24	47	—	Chlorite with poorly ordered
27 102-A (sandstone)	32	—	8	3	—	—	—	—	—	—	2	2	—	—	39	86					mix-layered smectite-illite
27 102-B (concretion)	Tr	—	—	—	12	—	—	—	—	—	—	—	—	—	12	—	—	—	—	—	mainly amorphous Fe oxides
Hell Creek Fm																					
36 106-C (shale)	26	—	3	2	2	—	—	—	—	Tr?	—	Tr?	—	64	97	—	—	—	100	—	
33 105-B (shale)	30	—	3	4	2	2	1	2	—	—	—	—	—	75	119	6	4	7	83		
33 105-C (shale)	40	—	6	13	—	—	—	3	—	—	—	—	—	23	85	—	Tr	67	—	33	
36 106-B (sandstone)	33	—	20	4	—	—	—	—	—	—	2	—	4	37	100	—	—	5	95		
17 75-B (shale)	30	—	5	2	—	—	—	3	—	—	—	—	—	63	103	—	19	41	40	—	
17 76-I (silty shale)	23	4	5	2	1	—	2	—	Tr	—	1	—	—	63		—	Tr	Tr	Tr	100	
17 75-F (limestone)	20	—	15	—	53	—	—	—	—	—	—	—	—	17	105						
17 75-C (silty shale)	29	—	2	4	—	—	—							61		12	14	45	29	—	
17 75-D (carbonaceous sh)	20	?	2	2	—	—	—							68	92	P	—	P	P	P	
17 76-M (sandy mudstone)	35	—	5	4	—	—	—							66	110	—	7	23	63	7	
17 75-A (sandy mudstone)	32	—	5	—			15							58	110	7	10	50	32	—	
Ludlow Fm																					
37 107-A_2	28	—	4	1	—	—	—	—	—	—	—	18[1]	—	57	108	8	Tr	39	53	—	
17 77-B (silty shale)	11	—	—	9	48	—	6	3	—	—	—	—	—	14	91	P	P	P	P	P	clay analyses not run
17 77-A (silty mudstone)	20	?	2	1	—	2?	1	—	4	?	1	—	4	45	80	—	—	8	67	25	
17 77-D (shale break)	41	—	Tr	Tr	—	—	—	—	—	—	—	—	—	59	100	28	—	29	17	26	
17 78-D (carbonaceous sh)	34	—	3	4	—	—	Tr	—	1	—	—	3[1]	—	70	115	[illegible]	—	71	29	—	
17 77-C (clayey sand)	32	—	6	2	—	5	2	—	7	—	—	—	—	55	109	27	Tr	56	17	—	
17 78-A (silty shale)	29	—	2	3	—	4	—	1	—	—	—	—	—	49	88						
Cannonball Fm																					
38 107-A_1 (soil)	26	2	3	2	20	—	6	Tr	—	—	—	—	—	34	93			P			clay analyses not run
38 107-C (concretion)	8	—	—	—	62	—	3	3	—	—	—	—	—	9	85						
39 108-A (shale)	28	—	8	2	5	—	19	2	1	—	—	—	—	58	123	16	—	60	24	—	
39 108-B (shale)	28	—	4	3	7	2	15	2	2	—	1	—	4	59	127	Tr	—	60	40	—	
40 108-C (shale)	30	—	21	4	26	—	—	—	—	—	—	—	—	31	112	Tr	—	28	72	—	
White River-Arikaree Grps																					two zeolites-
29 103-B (Arikaree)	12	4	4	3	19	5	—	8	—	—		11[2]	—	50	115	—	—	90	—	10	erionite and clinoptilolite
29 103-A (Arikaree)	41	—	4	5	23	—	—	3	—	—	—	5[3]	—	14	95						no clay peaks
29 103-C (White River)	9	2	3	8	15	—	—	3	—	—	—	—	Tr	59	99	—	—	25	75	—	

[1] Analcine [2] Erionite and clinoptilolite [3] Clinoptilolite

Plate 2 Mineralogic composition of rocks and soils (in percent estimated by X-ray diffraction)

The Carlile Shale is approximately 530 feet thick and the lower portion consists of dark-gray shale, some siltstones, and large limestone concretions. The upper Carlile is also a dark-gray shale, but three thin persistent sandstones are present in this part of the unit. The Carlile is composed primarily of clay minerals with subordinate amounts of quartz and trace amounts of numerous other minerals. One bentonite bed in the Carlile was sampled and was found to be unique in that it was essentially 100 percent kaolinite (Plate 2).

The Niobrara Formation consists of 225 feet of dark-gray calcareous marl with abundant white specks. On weathering the Niobrara turns a distinctive light yellow, which is due to the loss of organic material. The Niobrara is extremely fossiliferous and in some cases is composed almost entirely of foraminifera tests. The Niobrara is composed of equivalent amounts of calcite, dolomite, and clay minerals (Plate 2).

The Pierre Shale Formation which outcrops over much of the study area attains a maximum thickness of 1750 feet. It has been subdivided into three mapping units by Knechtel and Patterson (1962). The three units are the Gammon, Mitten, and an upper unit. The lowermost Gammon is composed of soft medium-gray shale with calcareous concretions and one bentonite bed. Thicknesses of up to 800 feet have been reported for the Gammon. Contained in the upper Gammon is the Groat Sandstone bed. It ranges in thickness from 50 to 150 feet and consists of gray to greenish-gray fine sand which weathers to a full gray-brown. Lying conformably on the Gammon is the Mitten black shale member which has a maximum thickness of 200 feet. It is composed of dark-gray to black shale with abundant calcareous concretions. The Mitten also contains a bentonite zone near the base. When weathered the Mitten is a dull brown and the concretions weather to a yellow-brown. One mapping unit was used by Knechtel and Patterson (1962) for the upper Pierre. It has been subdivided in other areas, but in northwestern South Dakota the units were indistinguishable. The lower portion of the unit is composed of a sandy dark-gray shale which in some areas contains lenses of fine sand. The middle 150 feet (which is equivalent to the Monument Hill of other areas) consists of a bentonitic shale and contains numerous bentonite beds up to 1.5 feet thick. The upper part of this unit is approximately 200 feet thick and consists primarily of dark-gray, fissile shale which contains few concretions. The composition of the Pierre Shale is dominated by clay minerals with subordinate amounts of quartz and trace amounts of numerous other minerals. The clay fraction is primarily smectite and illite with smectite predominating. Several samples contained minor amounts of cristobalite (Plate 2).

A transitional contact is present between the Pierre and the overlying Fox Hills Sandstone. The Fox Hills is composed of yellow to red sandstone interbedded with clays and silts. The lower portion is rich in marine fossils whereas the upper portion represents a brackish water environment of deposition. The Fox Hills is composed chiefly of quartz with subordinate amounts of clay minerals. The clay fraction is dominated by smectite (Plate 2).

The Hell Creek Formation is the youngest Cretaceous unit in the area and consists of freshwater clays and sands which are dull brown and are commonly referred to as the "somber beds." This unit attains a maximum thickness of 550 feet. The Hell Creek is composed primarily of clay minerals and quartz. The clay fraction is chiefly smectite and illite (Plate 2).

The Ludlow Formation lies conformably on the Hell Creek and is the oldest Tertiary unit in the study area. It is composed of light colored sandstones and clays interbedded with many thin lignite beds. The Ludlow represents a terrestrial depositional environment. It attains a maximum thickness of 350 feet in northwestern South Dakota. The Ludlow is composed primarily of clay minerals and quartz. One sample contained abundant calcite. The formation was unique in that it was the only unit found to contain the zeolite analcime (Plate 2).

The Cannonball Formation is the marine equivalent of a portion of the Ludlow. It is composed of calcareous dark, sandy shale and represents the expansion of the Cannonball sea during the Paleocene. The presence of marine fossils is the primary criterion for differentiation from the Ludlow. The Cannonball is composed of clay minerals, quartz, and calcite (Plate 2).

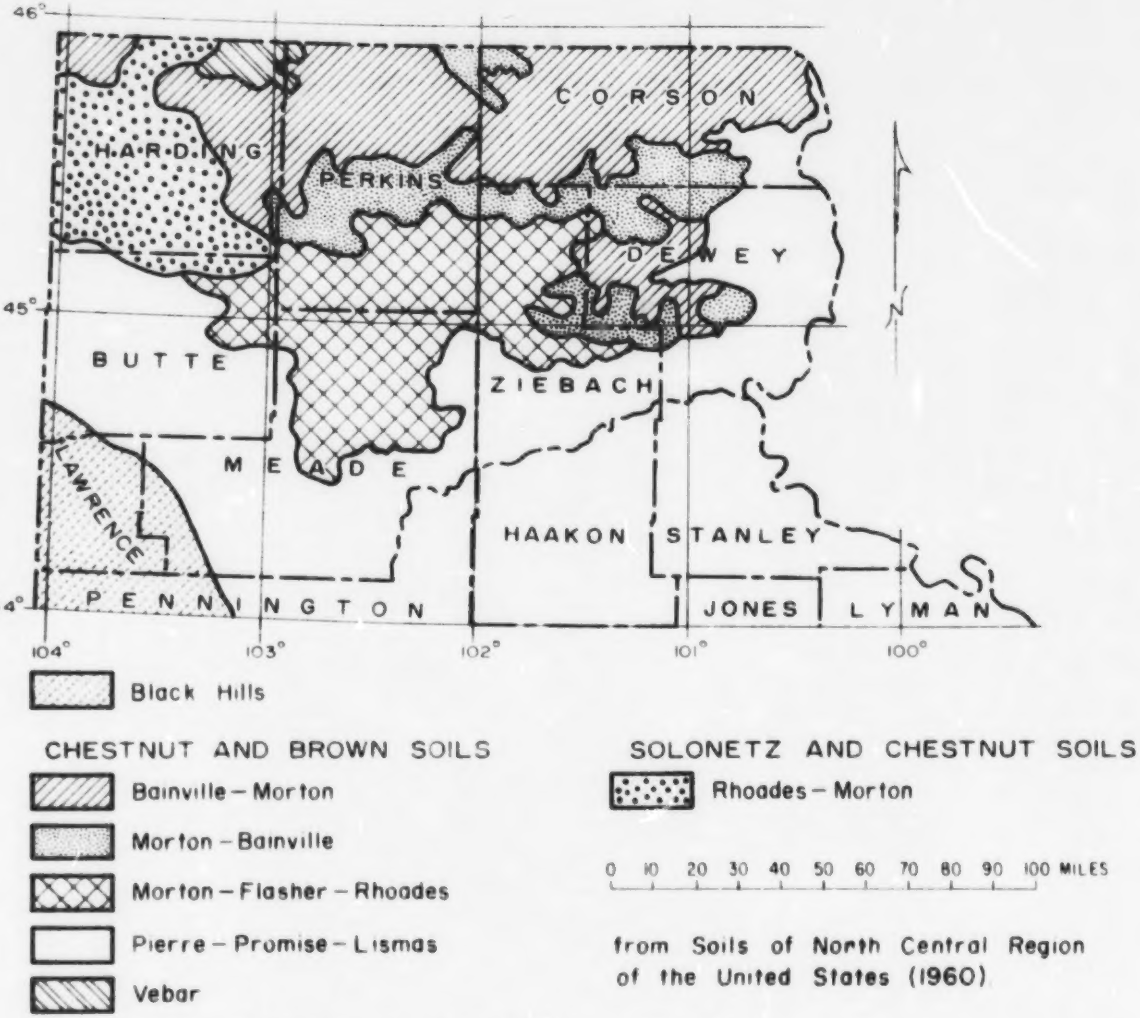
The Tongue River Formation, uppermost Paleocene unit in the area, is predominately a fine-grained sandstone up to 285 feet thick. The Tongue River lies conformably on the Ludlow and Cannonball and contains several lignites.

The White River Group (Miocene) is composed of up to 200 feet of light-colored clays and sandy clay. It is isolated on butte tops and is quite limited in areal extent.

Even more limited in areal extent is the Arikaree Group, which caps buttes in the study area. It is composed of very fine-grained sand and is up to 125 feet thick. Quartz, calcite, and clay minerals dominate the composition of these units. They are unique in that they contain the zeolites, erionite and clinoptilolite, as well as cristobalite (Plate 2).

SOILS

Five major soil associations are present in the study area; all are formed on Cretaceous and Tertiary rocks with the exception of a small area near the Black Hills (Figure 8). These soil associations, as indicated on the map, are Bainville-Morton, Morton-Bainville, Morton-Flasher-Rhoades, Pierre-Promise-Lismas, and Rhoades-Morton. As all the soils in the area are developed in a semi-arid, temperate climate, they are quite thin and strongly reflect the nature of the parent rock. Because of this a knowledge of the geology of the area is essential when using soils data. All of the soils are excessively to well drained with the exception of the Rhoades-Morton association, which has developed on Tertiary rocks in the northwestern corner of


46°
45°
44°
104°
103°
102°
101°
100°
HARDING
PERKINS
CORSON
DEWEY
BUTTE
ZIEBACH
MEADE
LAWRENCE
PENNINGTON
HAAKON
STANLEY
JONES
LYMAN
Black Hills
CHESTNUT AND BROWN SOILS
Bainville – Morton
Morton – Bainville
Morton – Flasher – Rhoades
Pierre – Promise – Lismas
Vebar
SOLONETZ AND CHESTNUT SOILS
Rhoades – Morton
0 10 20 30 40 50 60 70 80 90 100 MILES

from Soils of North Central Region of the United States (1960)

Figure 8 Generalized soils map of study area

the State. In this area the drainage is sufficiently immature to provide large areas of undissected table lands where this type of soil develops. Mineralogy of the soils was found to correspond with the mineralogy of the parent rock (Plate 2).

VEGETATION

A major portion of the study area is covered by mid-length and short prairie grasses and the major agricultural activity is ranching. What farming is done is mostly small grain production. Trees are found only in stream valleys and groves planted as windbreaks. Cottonwood, willow, and cedar are the true varieties found most often in the drainages. The Black Hills, South and North Cave Hills, and Slim Buttes form small isolated patches of western coniferous forest.

The cottonwood trees were sampled in that they are phreatophytes and they would reflect the quality of the ground water. Selected trace element composition of cottonwood leaf samples are given in Table 1. Anomalously high arsenic concentrations were found in cottonwood leaves collected at Site 13 (Sample L2) on Whitewood Creek. Another anomaly is the high strontium, selenium, and mercury levels found in leaves collected from Site 16 (Sample L5) on Cherry Creek.

WATER CHEMISTRY

Water quality data are presented in Tables 2 and 3.

A correspondence was found between water quality and rock type. That is, streams draining areas of marine formations have a calcium and/or magnesium sulfate type water while areas dominated by continental deposits have sodium bicarbonate water (Table 4). This difference in water quality also appears in the ground water. Data presented by Denson and Gill (1965) for wells and springs in the Hell Creek and Fort Union Formations (Ludlow Formation of this report) show sodium as the major cation in the ground water. Denson and Gill also report springs issuing from the tuffaceous White River and Arikaree Groups contain up to 70 parts per billion (ppb) arsenic and selenium. With the exception of Whitewood Creek, which has been contaminated by arsenic bearing mine tailings, arsenic levels above the detection limits of 30 ppb were not encountered in the sampled streams. Because of analytical restrictions selenium was not determined for the water samples; but in view of the high selenium levels found in the rocks and soils (see Table 5) any future studies should place a high priority on selenium analyses.

Other than the high trace element content of Whitewood Creek, the major drawback to the surface water is the high salinity. With the exception of Spearfish Creek, none of the streams meet the federally recommended limit to 500 parts per million (ppm) total dissolved solids (TDS). The high salt content of the streams is due in part to the low flows and drought encountered during sampling;

SAMPLE	Cadmium	Chromium	Strontium	Copper	Lead	Nickel	Arsenic	Selenium	Mercury	
L1-N. Fork Grand R.	2.0	<20	<10	5.0	<10	<5	<0.15	0.47	0.04	
L2 Whitewood Cr.	0.5	<20	<10	2.0	<10	<5	0.50	0.09	0.04	
L3-Rabbit Cr.	1.0	<20	<10	5.0	<10	<5	0.15	2.80	0.04	
L4 Spearfish Cr.	0.5	<20	<10	2.0	<10	<5	0.15	1.20	0.04	
L5-Cherry Cr.	1.0	<20	400	3.0	<10	<5	<0.15	4.30	0.68	
L6-S. Fork Moreau R.	0.5	<20	<10	2.0	<10	<5	0.20	1.30	0.08	
L7 Cheyenne R.	0.5	<20	<10	2.0	<10	<5	<0.15	2.50	0.04	
L8-Owl Cr.	1.0	<20	<10	5.0	<10	<5	N. D.	1.50	0.08	
L9-S. Fork Grand R.	0.5	<20	10.0	5.0	<10	<5	N. D.	1.20	0.12	

N. D. = not determined

Table I. Selected trace element composition of cottonwood leaves.

SAMPLE SITE	Conductivity µohms	PARTS PER MILLION										
		T.D.S.	Na	K	Ca	Mg	Cl	SO_4	F	[1]	[2]	pH
1) N. Fork Grand R.	2800	3000	600	15	170	98	16	1300	1.7	393	0	8.2
2) S. Fork Grand R.	1925	2328	590	10	50	14	12	640	1.0	656	68	9.0
3) Rabbit Cr.	1500	1712	405	8	40	12	10	375	1.5	599	21	8.7
4) Antelope Cr.	1390	1532	340	10	120	7	10	270	1.25	604	12	8.6
5) N. Fork Moreau R.	800	696	220	5	30	5	6	240	0.5	252	0	8.3
6) S. Fork Moreau R.	2950	3200	660	13	120	50	16	1300	1.6	416	16	8.7
7) Jones Cr.	740	716	175	6	25	10	6	200	0.75	192	4	8.5
8) Bull Cr.	2375	2256	580	10	50	16	10	530	1.0	842	74	9.0
9) Grand R.-Buffalo	1900	1780	420	8	25	7	6	325	1.0	774	112	9.6
10) Camp Crook-L. Mo.	800	1128	215	8	160	37	8	520	1.0	224	0	8.3
11) Owl Cr.	2100	2900	265	10	580	136	10	2050	2.75	94	0	8.2
12) Indian Cr.	2175	2372	300	10	305	105	96	1230	1.5	164	0	8.2
13) Whitewood Cr.	680	548	120	20	130	40	12	195	± 1.0	172	2	8.4
14) Spearfish Cr.	250	424	16	1	110	35	4	10	<.2	200	8	8.5
15) Cheyenne R.	1900	1960	268	16	315	100	35	1230	1.5	124	0	8.3
16) Cherry Cr.	5400	6764	660	32	580	165	123	3900	4.1	231	0	7.7

[1] Total Alkalinity [2] Pheno Alkalinity

Table 2. Chemical Analyses of water sample majors in parts per million.

SAMPLE SITE	PARTS PER BILLION								
	Cu	Zn	Fe	Mn	As	Mo	Al	V	Hg
1) N. Fork Grand R.	<100	<40	50	50	<30	<10	40	11	<0.5
2) S. Fork Grand R.	<100	<40	200	100	<30	<10	40	20	1.2
3) Rabbit Cr.	<100	<40	150	<50	<30	<10	80	17	<0.5
4) Antelope Cr.	<100	60	1100	100	<30	<10	600+	20	1.2
5) N. Fork Moreau R.	<100	100	500	50	<30	[1]N. D.	[1]N. D.	[1]N. D.	N. D.
6) S. Fork Moreau R.	<100	<40	150	100	<30	<10	320	6	1.2
7) Jones Cr.	<100	60	350	<50	<30	<10	600+	10	<0.5
8) Bull Cr.	<100	<40	500	100	<30	<10	320	17	<0.5
9) Grand R - Buffalo	<100	<40	550	<50	<30	<10	440	17	<0.5
10) Camp Crook-L. Mo.	<100	<40	20	50	<30	<10	40	10	N. D.
11) Owl Cr.	<100	<40	50	<50	<30	<10	280	<5	<0.5
12) Indian Cr.	<100	<40	550	160	<30	<10	200	<5	<0.5
13) Whitewood Cr.	100	50	400	100	450	<10	320	<5	<0.5
14) Spearfish Cr.	<100	<40	50	<50	<30	<10	200	8	<0.5
15) Cheyenne R.	<100	<40	50	<50	<30	<10	<20	<5	<0.5
16) Cherry Cr.	<100	50	520	1900	<30	<10	440	<5	<0.5

[1] N. D. Not Determined

Table 3 Chemical Analyses of water sample minors in parts per billion.

Drainages	Carlile[1]	Niobrara[1]	Pierre[1]	Fox Hills[1]	Hell Creek[1]	Ludlow[1]	Cannonball[1]	Tongue River[1]	White R-Arik[1]	$\frac{Ca + Mg}{Na + K}$[2]	
N. Fork Moreau R.					371				10	0.20	
S. Fork Moreau R.		114	508		303				18	0.35	
Bull Cr.					51	16		3		0.15	
Jones Cr.					47	15				0.27	
Rabbit Cr.					119	194			32	0.17	
Indian Cr.			208							1.80	
Owl Cr.	29	18	58							3.40	
Cherry Cr.			986	1139	464	10				1.40	
Antelope Cr.					201	38			22	0.44	
N. Fork Grand R.						144	138+	136+		0.64	
S. Fork Grand R.					861	701	97	39	3	0.14	

[1] Area in square milles

[2] concentrations in milli-equivalents

Table 4. Areal distribution of geologic formations.

TABLE 5. Semi-Quantitative Analyses By X-Ray Fluorescence

(in parts per million)

Sample Number Geologic Unit	Copper	Zinc	Vanadium	Sulfur	Phosphorus	Manganese	Strontium	Arsenic	Selenium	Comments
Site 19 87B Inyan Kara Group	39	<40	83	875	580	103	440	<30	<30	Shale
Site 22 99B Carlile Shale	38	217	92	14,400	829	110	219	<30	<30	Shale
Site 23 100A Carlile Shale	37	565	87	3,170	1,021	385	150	<30	<30	Shale
Site 23 100C Niobrara Formation	28	60	50	890	46,558	577	520	<30	<30	Chalk
Site 25 101A Pierre Formation	36	215	85	3,280	846	1,722	110	<30	<30	Shale
Site 32 104C Pierre Formation	33	220	88	1,676	1,080	686	240	<30	<30	Shale
Site 30 103D Pierre Formation	35	205	93	1,183	804	166	176	<30	<30	Shale
Site 33 105A Fox Hills Formation	38	104	73	2,380	995	580	431	<30	<30	Clay rich, fine, sandstone
Site 27 102C Fox Hills Formation	38	56	72	620	1,288	820	438	<30	<30	Immature soil
Site 17 78J Hell Creek Formation	26	65	82	3,350	2,070	8,750	191	<30	<30	Clay rich silt
Site 17 78I Hell Creek Formation	35	184	86	2,000	718	1,671	270	<30	<30	Silty clay
Site 17 77D Ludlow Formation	41	75	76	274	120	89	155	<30	<30	Lignitic zone
Site 17 77C Ludlow Formation	28	112	75	1,177	514	240	57	<30	<30	Clay rich sand
Site 17 77B Ludlow Formation	28	<40	40	720	52,229	4,270	185	<30	<30	Fine sandstone
Site 17 77A Ludlow Formation	39	182	100	9,465	689	173	163	<30	<30	Mudstone
Site 17 78A Ludlow Formation	41	97	75	2,229	94	166	459	<30	<30	Mudstone
Site 27 107B$_2$ Tongue River Formation	34	<40	57	810	3,170	300	136	<30	<30	Sandstone
Site 29 103C White River Group	35	193	59	600	3,156	738	424	<30	<30	Clay

but on the basis of one sampling period, it is impossible to evaluate what the "normal" water quality is.

GEOCHEMISTRY

Trace element contents of rocks and soils are given in Tables 5 and 6. Trace element content of vegetation samples are given in Table 1. Trace element composition of lignites and carbonaceous shales is reported in Table 7.

Due to the reconnaissance nature of this study, the large area studied, and the large diversity of rock age and rock type, no meaningful trends were immediately apparent.

The most potentially hazardous anomaly noted is the high selenium values (arithmetic mean 7.9 ppm). Shacklette, et al., 1974, reports an arithmetic mean for selenium values in soils and surficial materials in the conterminous United States of 0.45 ppm. The same authors report an arithmetic mean of 7.4 for arsenic contents in surficial materials, whereas the samples in this study report the arithmetic mean is 20.1 ppm arsenic.

These high selenium values were expected, as the rocks of the upper Great Plains and particularly South Dakota have been known to have high selenium contents. Data presented by Moxon, et al., 1950, indicate the Paleozoic rocks in South Dakota contain little selenium (<1.0 ppm). Data from the same source indicate that the Triassic and Jurassic systems have low selenium contents. The Inyan Kara and Graneros Groups are also low in selenium content but locally may have high selenium contents. The Greenhorn Formation contains a low concentration of selenium but more than the underlying formations with a maximum reported value of 6 ppm. The Carlile Formation contains low selenium content but is rarely selenium free; the maximum reported value is 3 ppm. The Niobrara Formation is a persistently highly seleniferous unit in the upper Great Plains with concentrations of 113 ppm reported by Moxon, et al. and unpublished data by the authors of 700 ppm in the eastern part of the State. The Pierre Formation has been studied in detail; and due to this intense study, a wide variability in selenium content has been found. The other units may also have this variability; but due to the lack of analyses, general statements cannot be made in this respect. Selenium contents range from <0.5 to 52 ppm for the Pierre Formation.

The Fox Hills Formation has received little study with respect to selenium content but is believed to be quite low; the maximum selenium value reported is 1.5 ppm.

The Hell Creek Formation reportedly has a low selenium content, but our data indicate moderate selenium content with a high of 9.8 ppm in a carbonaceous shale.

Sample number and geologic unit.	Mercury[1]	Arsenic[2]	Selenium[3]	Description
20-98A Spearfish Fm.	N.D.[4]	7	<1	sndy., slty. sh.
19-97B Inyan Kara Grp.	0.06	42	7.6	sh.
23-100A Carlile Fm.	0.03	8	1.5	sh.
23-100C Niobrara Fm.	0.02	2	5.6	ch.
25-101A Pierre Fm.	0.05	20	3.3	sh.
30-103E Pierre Fm.	0.06	20	4.9	immature soil
30-103D Pierre Fm.	0.10	35	8.8	sh.
32-104C Pierre Fm.	0.12	11	8.8	sh.
27-102C Fox Hills Fm.	0.04	20	<1	immature soil
17-75A Hell Creek Fm.	0.05	8	2.4	clay rich ss.
17-75D Hell Creek Fm.	N.D.[4]	5	9.8	carb. sh.
17-77D Ludlow Fm.	0.11	11	7.7	lignite zone
17-78A Ludlow Fm.	0.03	20	6.4	mudst.
37-107A$_2$ Ludlow Fm.	0.08	21	30.2	carb. sh.
17-77A Ludlow Fm.	0.12	100	N.D.[4]	slty. mudst.
17-77B Ludlow Fm.	0.03	2	8.8	fine ss.
17-77C Ludlow Fm.	0.05	5	10.5	clay rich ss.
40-108C Cannonball Fm.	0.02	8	3.8	clay rich ss.
39-108C Cannonball Fm.	0.03	38	20.9	sh.
29-103C White River Grp.	0.07	19	N.D.[4]	

[1] Mercury by flameless atomic absorption.

[2, 3] Arsenic by an arsine evolution-spectrophotometric method. Selenium by a chemical-X ray fluorescence method as described in Shacklette et al (1974).

[4] N.D. - not determined.

Table 6. Concentrations of Mercury, Arsenic, and Selenium in parts per million.

SAMPLE	Percent Ash	Copper	Selenium	Arsenic	Vanadium	Lead	Cadmium	Chromium	Cobalt	Strontium	Nickel	Zinc	Mercury	
Site 17-76H	6	<0.1	<1.0	6.0	17.5	5	1	<10	5	100	<10	18	<0.04	
Site 17-76K	21	15.0	N. D.	20.0	15.0	12	1	<10	15	50	20	28	<0.04	
Site 17-76N	34	30.0	<1.0	22.5	30.0	18	1	<10	15	<50	<10	28	<0.04	
Site 17-77E	22	23.0	3.0	7.0	22.5	18	1	<10	15	<50	<10	43	0.10	
Site 17-77F	11	18.0	<1.0	8.3	7.5	20	1	<10	15	50	20	210	0.55	
Site 17-77G	23	20.0	<1.0	5.0	17.0	43	1	<10	15	<50	<10	21	<0.04	
Site 17-77D	60	13.0	N. D.	4.0	32.5	18	2	<10	15	<50	<10	32	<0.04	
Site 17-78C	26	10.0	10.0	46.0	12.5	30	2	<10	20	100	<10	46	0.20	
Avg. values[1]	16	32.0	N. D.	8.0[2]	32.0	6.4	N. D.	6.4	3.2	160	16	N. D.	N. D.	

[1] Average values for relatively unmineralized lignite at Slim Buttes, S. D. (Denson and Gill, 1965)

[2] Based on detection in so few samples that average is of limited significance.

Table 7. Ash content and selected trace element composition of lignites and carbonaceous shales in parts per million.

Selenium distribution in the Ludlow Formation is erratic and appears dependent on the type of lithology sampled with maximum 30.2 ppm in a carbonaceous shale. Selenium content of the Cannonball Formation is moderate with a maximum of 3.8 ppm.

The Tongue River Formation apparently contains little selenium, with maximum reported value of 0.5 ppm.

White River and Arikaree Groups contain moderate amounts of selenium, with a maximum reported value of 9 ppm.

Much of the geochemical work in the area has been done on selenium; therefore, the above discussion was possible. For elements other than uranium, which has been studied in detail in mineralized areas, there is a paucity of data. The limited number of samples analyzed in this study precludes the compilation of a geochemical map per se; other than to refer the reader to the analysis of each geologic unit in Table 5, the above selenium discussion, and the geologic map (Plate 1).

EVALUATION OF REMOTE SENSING FOR SITE SELECTION

Remote sensing in the form of aerial photographs has been used for years by geologists in compiling geologic maps.

In the present study geologic quadrangle maps of the South Dakota Geological Survey were used in selecting sample sites. Aerial photographs were used as a base for preparing these maps; thus, remote sensing of this type was used indirectly in selecting sample sites. Because of the large area under study, aerial photos were not used in the field work. In a study of this nature, aerial photos are inconvenient and cumbersome for field use because of the large number of photos required. In a smaller, more detailed study where geologic maps are lacking, a combination of topographic maps and aerial photos would be very useful.

ERTS photography and Skylab photos are available but were of too small a scale to be of any value to this type of sampling.

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APPENDIX

The water samples were collected in two forms; one being filtered through a 0.45 micron membrane filter and then treated with nitric acid to a pH of less than 3.0; the other sample was untreated except for the addition of 2 milliliters of formaldehyde per liter. Stream sediment samples were collected below the water level and sealed in air tight plastic bags. Geologic samples and vegetation samples were also placed in air tight plastic bags.

Site 1

North Fork Grand River NE¼ SW¼ NW¼ NW¼ sec. 11, T. 21 N., R. 14 E., June 25, 1974. Time 1200 CDT.
SITE LOCATION - samples collected 10 feet from east side of bridge on south bank of stream.
SAMPLES - one water filtered and treated with nitric acid; one water "raw" treated with formaldehyde; one stream sediment sample; one sample of cottonwood leaves.
COMMENTS - U.S.G.S. stream gauging station on west side of bridge north bank. Valley cut in Ludlow; surrounding geology mapped as Ludlow-Cannonball transition facies (see Haynes quadrangle).

Site 2

South Fork Grand River SW¼ SW¼ SW¼ NW¼ sec. 18, T. 19 N., R. 14 E., June 25, 1974. Time 1315 CDT.
SITE LOCATION - samples collected on north bank 10 feet east of bridge.
SAMPLES - one water filtered and treated with nitric acid; one water "raw" treated with formaldehyde; one stream sediment sample; one sample of cottonwood leaves.
COMMENTS - broad valley floored with upper Hell Creek (see Bison quadrangle).

Site 3

Rabbit Creek SE¼ SE¼ NE¼ NE¼ sec. 6, T. 16 N., R. 13 E., June 25, 1974. Time 1430 CDT.
SITE LOCATION - samples collected from south bank immediately east of bridge.
SAMPLES - one water filtered and treated with nitric acid; one water "raw" treated with formaldehyde; one stream sediment sample; one sample of cottonwood leaves.
COMMENTS - valley is in upper Hell Creek, good exposures in north cutbank and south valley wall (see Date quadrangle).

Site 4

Antelope Creek SW¼ SW¼ NW¼ NW¼ sec. 32, T. 16 N., R. 13 E., June 25, 1974. Time 1600 CDT.
SITE LOCATION - 50 feet east of bridge on south bank.
SAMPLES - one water filtered and treated with nitric acid; one water "raw" treated with formaldehyde.
COMMENTS - valley is in upper Hell Creek. Only 500 ml of water was filtered and acidified due to high suspended load of water (see Date quadrangle).

Site 5

North Fork Moreau River SW¼ NW¼ NE¼ NE¼ sec. 17, T. 14 N., R. 10 E., June 25, 1974. Time 1730 CFT.
SITE LOCATION - south bank 10 feet east of bridge.
SAMPLES - one water sample "raw" treated with formaldehyde; due to high suspended load 3 liters were collected, treated with formaldehyde, later cooled, decanted and filtered at motel in evening and then acidified. One stream sediment sample.
COMMENTS - valley is in Hell Creek (see Zeona quadrangle).

Site 6

South Fork Moreau River SE¼ NW¼ SE¼ NE¼ sec. 16, T. 13 N., R. 10 E., June 25, 1974. Time 1845 CDT.
SITE LOCATION - north bank 10 feet to the northeast of bridge.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample, one sample cottonwood leaves.
COMMENTS - valley is in Fox Hills (see Zeona quadrangle).

Site 7

Jones Creek SW¼ SW¼ NE¼ SE¼ sec. 12, T. 20 N., R. 4 E., June 26, 1974. Time 1530 CDT.
SITE LOCATION - south bank 30 feet east of culvert.
SAMPLES - one water sample filtered and treated with nitric acid (collected approximately 600 ml because of high turbidity); one water sample "raw" treated with formaldehyde; one stream sediment sample.
COMMENTS - creek had limited flow. Valley is in Hell Creek (see Buffalo quadrangle).

Site 8

Bull Creek NE¼ NE¼ NW¼ SW¼ sec. 11, T. 21 N., R. 4E., June 26, 1974. Time 1630 CDT.
SITE LOCATION - south bank 10 feet west of bridge.

Site 8 -- continued.

SAMPLES - one water sample filtered and acidified; one water sample "raw" treated with formaldehyde; one stream sediment.
COMMENTS - valley in Hell Creek; limited flow in creek (see Ladner quadrangle).

Site 9

Little Grand River (South Fork Grand River) SW¼ NW¼ SW¼ SW¼ sec. 29, T. 19 N., R. 5 E., June 26, 1974. Time 1730 CDT.
SITE LOCATION - south bank 50 feet east of bridge.
SAMPLES - one water sample filtered and treated with nitric acid one water sample "raw" treated with formaldehyde; one stream sediment sample.
COMMENTS - U.S.G.S. gauging station south end, east side of bridge. Valley in Hell Creek (see Buffalo quadrangle).

Site 10

Little Missouri River NE¼ SE¼ SW¼ SW¼ sec. 2, T. 18 N., R. 1 E., June 27, 1974. Tiem 0915 CDT.
SITE LOCATION - west bank 25 feet south of bridge.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample.
COMMENTS - U.S.G.S. gauging station south side, west end of bridge. Valley in Hell Creek (see Camp Crook and Midland No. 4 quadrangle).

Site 11

Owl Creek NW¼ NW¼ NW¼ NE¼ sec. 14, T. 10 N., R. 2 E., June 27, 1974. Time 1230 CDT.
SITE LOCATION - east bank 10 feet north of bridge.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample; one sample cottonwood leaves.
COMMENTS - no surface flow of water. Stream flows along Niobrara Chalk-Pierre Shale contact.

Site 12

Indian Creek NE¼ NE¼ NW¼ sec. 33, T. 11 N., R. 3 E., June 27, 1974. Time 1440 CDT.
SITE LOCATION - north bank 50 feet east of bridge.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample.
COMMENTS - good flow in creek; steam flows on Pierre Shale.

Site 13

Whitewood Creek NE¼ NE¼ NW¼ sec. 27, T. 6 N., R. 4 E., June 27, 1974. Time 1630 CDT.
SITE LOCATION - East bank 30 feet south of bridge.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample; one sample cottonwood leaves.
COMMENTS - water very turbid but it filtered easily.

Site 14

Spearfish Creek SW¼ SW¼ SW¼ sec. 34, T. 7N., R. 2 E., June 27, 1974. Time 1730 CDT.
SITE LOCATION - downstream at end of wing wall of diversion dam.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample; one sample cottonwood leaves.
COMMENTS - numerous trout in stream.

Site 15

Cheyenne River NW¼ NW¼ NE¼ sec. 34, T. 7 N., R. 18 E., June 28, 1974. Time 0930 CDT.
SITE LOCATION - south bank 100 feet east of bridge.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample; one sample cottonwood leaves.
COMMENTS - stream flows on Pierre Shale.

Site 16

Cherry Creek SE¼ SE¼ SW¼ sec. 31, T. 8 N., R. 22 E., June 28, 1974. Time 1030 CDT.
SITE LOCATION - "pot hole" 100 feet north of bridge.
SAMPLES - one water sample filtered and treated with nitric acid; one water sample "raw" treated with formaldehyde; one stream sediment sample; one sample cottonwood leaves.
COMMENTS - no flow in creek; water collected from "pot hole" had a brownish color. Stream is in Pierre Shale.

Site 17

Rattlesnake Butte NW¼ NE¼ SE¼ NE¼ sec. 28, T. 20 N., R. 4 E., June 29, 1974.
SITE LOCATION - south side east end of butte; section starts in gully at base of butte.
SAMPLES - 12 samples from Hell Creek; 11 samples from Ludlow; 1 sample from Tongue River (see columnar section at end of appendix); 1 soil sample from just east of butte (developed on Ludlow); 1 prickly pear growing by soil sample.

Site 17 -- continued.

COMMENTS - this site is a detailed geologic section. The section was measured and sampled on a scale of centimeters. The section consists of 21 meters of upper Hell Creek; a complete Ludlow section (56 meters); and an estimated 40 meters of Tongue River (not measured in detail).

Site 18

Graneros Group - center sec. 22, T. 8 N., R. 2 E.
SITE LOCATION - just south of junction of Highway 34 and 85, across from Sunset Motel. Sample collected from an approximately 5-meter exposure in west roadcut.
SAMPLES - 97A - one sample of dark-gray shale; slightly silty; weathers to silvery-gray flakes.
COMMENTS - sample collected about road level. Outcrops partly covered with small Ponderosa Pine (0.5-1 meter high).

Site 19

Inyan Kara Group - NE¼ sec. 34, T. 8 N., R. 2 E.
SITE LOCATION - abandoned clay pit(?). Samples collected 60 meters northeast of rifle range on north wall of the pit.
SAMPLES - 97B - one sample of greenish-gray shale mottled with reds and purple (unit 5 meters thick); 97C - one sample of carbonaceous shale with abundant plant fragments (1 meter thick); 97D - one sample of noncalcareous, fine-grained, tan sandstone.
COMMENTS - believe the greenish shale is material which was used for manufacturing brick.

Site 20

Spearfish Formation - SW¼ sec. 34, T. 7 N., R. 2 E.
SITE LOCATION - just east of Spearfish Creek on south facing slope approximately 200 meters north of I-90.
SAMPLES - 98A - one sample of rusty-red very silty and sandy shale taken 9 meters up from break in slope; 98B - one soil sample taken 12 meters up from break; 98C - one sample taken of fine- to medium-grained gypsum bed (3 meters thick).
COMMENTS - the soil sample is from grassed area in the middle of section; very poor soil development. The gypsum bed at top is the Gypsum Springs Formation and is weathered.

Site 21

Greenhorn Formation - SE¼ SE¼ sec. 15, T. 9 N., R. 2 E.
SITE LOCATION - outcrop west side of road approximately 100 meters from fence; south facing slope in small gully.
SAMPLES - 99A - one sample taken of brownish-gray soft marl.
COMMENTS - poor outcrop, sample is partly weathered.

Site 22

Carlile Shale - SW¼ SW¼ sec. 35, T. 10 N., R. 2 E.
SITE LOCATION - north valley wall of Salt Creek, small roadcut east side of road.
SAMPLES - 99B - one sample of noncalcareous dark medium gray shale. Gypsum along bedding planes, sample slightly weathered.
COMMENTS - sample is from about the middle of the formation.

Site 23

Niobrara and Carlile Formations - NW¼ NE¼ sec. 15, T. 10 N., R. 2 E.
SITE LOCATION - in east cutbank just south of Highway 85 at Niobrara-Carlile contact.
SAMPLES - 100C - one sample Niobrara Chalk; 100A - one sample Carlile Shale; and 100B - one sample of bentonite.
COMMENTS - estimate 1-2 meters of both units are exposed with an apparent dip of 12^0 to the northwest. The Niobrara is thinly bedded and weathered to a buff. The Carlile is dark medium gray and is slightly weathered.

Site 24

Pierre Shale - NE¼ SW¼ sec. 2, T. 11 N., R. 4 E.
SITE LOCATION - north of road in small roadcut west bank of Horse Creek.
SAMPLES - 100D - one sample dark medium gray shale, noncalcareous; weathers to a yellowish-grayish brown.
COMMENTS - sample from upper 100-200 meters of Pierre Shale. Whole area has very few outcrops.

Site 25

Pierre Shale - NW¼ NW¼ sec. 9, T. 11 N., R. 3 E.
SITE LOCATION - east side of road in small roadcut.
SAMPLES - 101A - one sample of dark medium gray, noncalcareous shale that weathers to a yellowish-brown; 101B - one sample of concretion.
COMMENTS - sample from upper 150-200 meters of the Pierre Shale.

Site 26

Colluvium developed on Pierre Shale - NW¼ SW¼ sec. 31, T. 11 N., R. 3 E.
SITE LOCATION - north flank of Mud Butte.
SAMPLES - 101C - one sample of surface colluvium coated with white efflorescence.
COMMENTS - efflorescence spots up to 1 meter in diameter.

Site 27

Fox Hills Formation - NW¼ SW¼ sec. 11, T. 16 N., R. 1 E.
SITE LOCATION - east side of road in small roadcut.
SAMPLES - 102A - one sample of poorly consolidated, yellowish-brown, noncalcareous, fine to medium sandstone; 102B - one sample concretions that weather reddish brown; 102C - one soil sample.
COMMENTS - approximately 5 meters of sandstone exposed; very poor soil development.

Site 28

Pierre Shale - SE¼ NE¼ sec. 10, T. 16 N., R. 1 E.
SITE LOCATION - approximately 50 meters north of site 27 west side of road, south bank of the creek.
SAMPLES - 102E - one sample of banded medium gray - dark gray, moderately calcareous shale approximately 5 meters below Fox Hills contact; 102D - one sample of bentonite just below shale sample.
COMMENTS - shale is very similar in appearance to Hell Creek.

Site 29

White River Group and Arikaree Group(?) - S½ sec. 31, T. 17 N., R. 2 E.
SITE LOCATION - southwest end of West Short Pine Hills; in major draw just up from small stock dam.
SAMPLES - 103A - one sample of clay rich siltstone (Arikaree Group?); 103B - one sample of greenish sandy, silty clay; and 103C - one sample of pinkish clay (White River Group).
COMMENTS - estimate 20 meters of Arikaree Group? and about the same of White River Group exposed at this locale.

Site 30

Pierre Shale - NE¼ sec. 19, T. 15 N., R. 2 E.
SITE LOCATION - east side of road, south side of creek, in a small roadcut.
SAMPLES - 103D - one sample of dark medium gray shale; 103E - one sample of soil.
COMMENTS - upper Pierre Shale; poor soil development.

Site 31

Pierre Shale - NE¼ sec. 29, T. 13 N., R. 2 E.
SITE LOCATION - small roadcut east side of road.
SAMPLES - 104A - one sample of noncalcareous, tan shale; moderately weathered; 104B - one sample of surface "popcorn."
COMMENTS - unit weathers to form a "frothy" popcorn surface; vegetation is very sparse.

Site 32

Pierre Shale - SE¼ sec. 21, T. 12 N., R. 2 E.
SITE LOCATION - small gully in west ditch, south valley wall.
SAMPLES - 104C - one sample of slightly silty and calcareous tan shale.
COMMENTS - weathers to popcorn surface.

Site 33

Transition zone Fox Hills-Hell Creek - SW¼ sec. 35, T. 13 N., R. 7 E.
SITE LOCATION - west side of road in undercut bank.
SAMPLES - 105A - one sample clay rich, poorly consolidated fine, gray sandstone; 105B - one sample of medium gray claystone; 105C - one sample of soil developed on sandstone.
COMMENTS - alternating sandstone and clay beds (1 meter thick); very poor soil development.

Site 34

Pierre Shale - SW¼ sec. 23, T. 13 N., R. 7 E.
SITE LOCATION - just north of road in east facing cutbank.
SAMPLES - 105D - one sample of medium gray noncalcareous shale; 105E - one sample of concretion; 105F - one sample of white salt accumulation around standing pool.
COMMENTS - shale sample is just down from Fox Hills contact. Salt crust is several centimeters thick.

Site 35

Pierre Shale - center sec. 4, T. 13 N., R. 7 E.
SITE LOCATION - just south of old bridge over Moreau River west side of road in roadcut.
SAMPLES - 106A - one sample of brown, noncalcareous shale; slightly(?) weathered.
COMMENTS - close to contact with Fox Hills.

Site 36

Hell Creek Formation - center sec. 22, T. 14 N., R. 7 E.
SITE LOCATION - east side of road in Badlands.
SAMPLES - 106B - one sample of yellowish-brown, poorly consolidated, fine-medium sandstone; 106C - one sample of dark gray "somber" beds.
COMMENTS - estimate 10 meters of sandstone underlain by 20 to 30 meters of predominately clay somber beds.

Site 37

Tongue River and Ludlow Formations - NW¼ sec. 26, T. 22 N., R 5 E.
SITE LOCATION - in the middle of Riley Pass.

Site 37 -- continued.

SAMPLES - $107B_2$ - one sample of moderately cemented, noncalcareous, massive, yellowish-tan sandstone (Tongue River); $107A_2$ - one sample of dark gray, noncalcareous, carbonaceous shale (Ludlow).
COMMENTS - both samples are spaced about 2 meters away from the contact.

Site 38

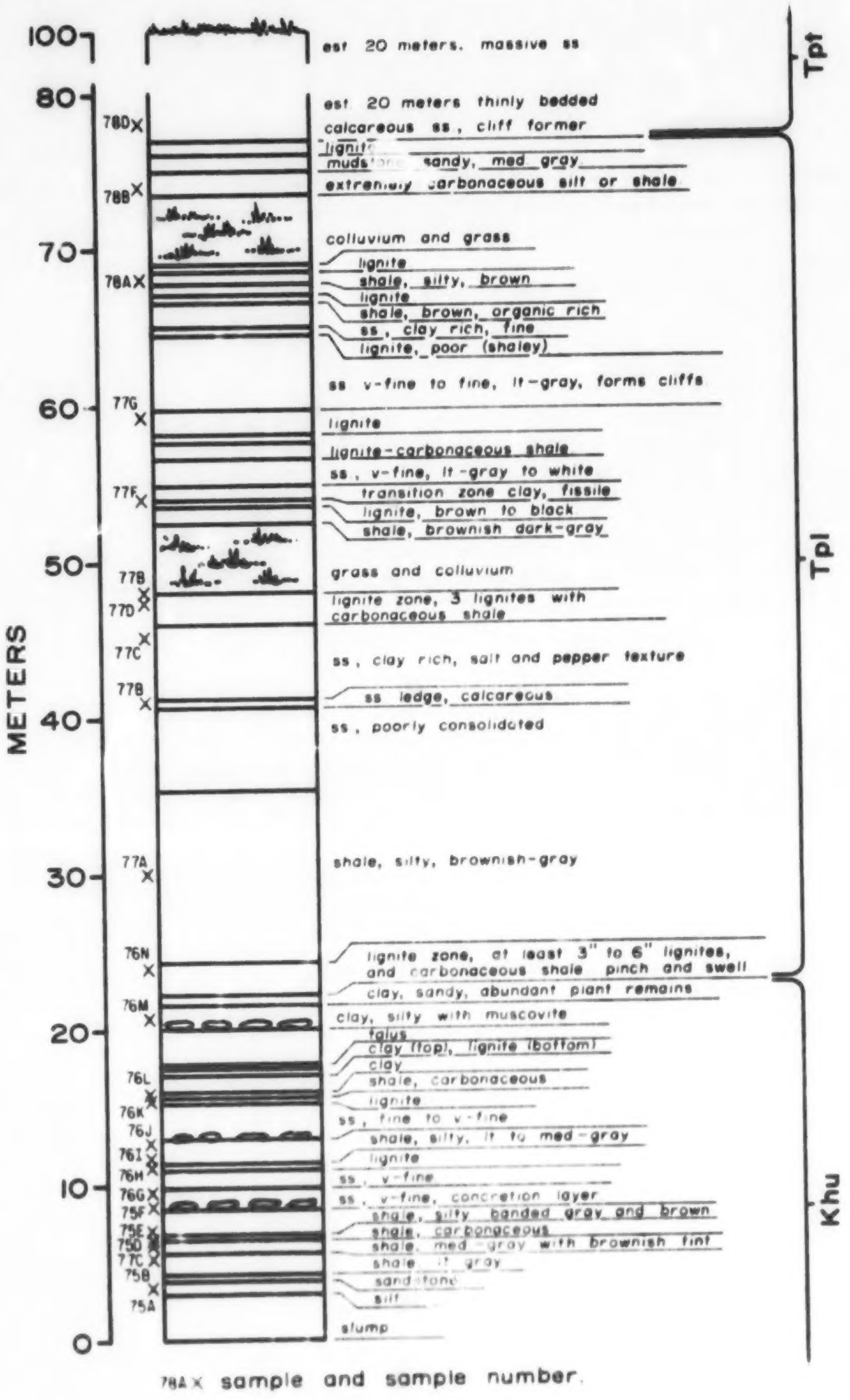
Cannonball Formation - SW¼ SE¼ sec. 2, T. 22 N., R. 9 E.
SITE LOCATION - small roadcut on north side of road.
SAMPLES - $107B_1$ - one sample of clay rich calcareous, tan siltstone; 107C - one sample of concretion; $107A_1$ - one sample of soil.
COMMENTS - exposures are extremely rare; but Cannonball forms a soil suitable for farming and the distribution is marked by fields under cultivation.

Site 39

Cannonball Formation - NW¼ NW¼ sec. 11, T. 21 N., R. 9 E.
SITE LOCATION - east side of road in roadcut at crest of ridge.
SAMPLES - 108A - one sample from the base of a brownish-gray, calcareous, silty, sandy shale; 108B - another sample from the top of exposure.
COMMENTS - surrounding area under cultivation.

Site 40

Cannonball Formation - NE¼ NE¼ sec. 34, T. 22 N., R. 10 E.
SITE LOCATION - small roadcut south side of road just west of bend in road.
SAMPLES - 108C - one sample clay rich, calcareous brown sandstone.
COMMENTS - concretionary litter on surface.


100
80
70
60
50
40
30
20
10
0
METERS
est 20 meters. massive ss
est 20 meters thinly bedded
calcareous ss, cliff former
lignite
mudstone sandy, med gray
extremely carbonaceous silt or shale
colluvium and grass
lignite
shale, silty, brown
lignite
shale, brown, organic rich
ss, clay rich, fine
lignite, poor (shaley)
ss v-fine to fine, lt-gray, forms cliffs
lignite
lignite-carbonaceous shale
ss, v-fine, lt-gray to white
transition zone clay, fissile
lignite, brown to black
shale, brownish dark-gray
grass and colluvium
lignite zone, 3 lignites with carbonaceous shale
ss, clay rich, salt and pepper texture
ss ledge, calcareous
ss, poorly consolidated
shale, silty, brownish-gray
lignite zone, at least 3" to 6" lignites, and carbonaceous shale pinch and swell
clay, sandy, abundant plant remains
clay, silty with muscovite
talus
clay (top), lignite (bottom)
clay
shale, carbonaceous
lignite
ss, fine to v-fine
shale, silty, lt to med-gray
lignite
ss, v-fine
ss, v-fine, concretion layer
shale, silty banded gray and brown
shale, carbonaceous
shale, med-gray with brownish tint
shale, lt gray
sandstone
silt
slump
78D
78B
78A
77G
77F
77E
77D
77C
77B
77A
76N
76M
76L
76K
76J
76I
76H
76G
75F
75E
75D
77C
75B
75A
Tpt
Tpl
Khu
78A X sample and sample number.

Site 17 - Geologic section measured on the south side of Rattlesnake Butte. (SW 1/4 SE 1/4 NE 1/4 NE 1/4 sec. 28, T. 20 N. - R. 4 E.)